Landscape series: 1

Spatial Developments in the Aruban Landscape:
A multidisciplinary GIS-oriented approach

Photo: Tree Lizard (Anolis lineatus (Latin), Toteki/Waltaca (local names), Gestreepte Boomhagedis (Dutch)
Photo: Ruud Derix, 2003

The Aruban landscape has undergone many changes in history and still serves as environmental backbone to the society. It plays a vital link and bonds together the social and economic wellbeing and prosperity. In this paper we introduce and summarize the topics that we describe in detail in a series of six publications on the Aruban Landscape.

2016

Contents

"A sustainable landscape basically suggests a managed balance in local nature that serves the needs of a dynamic society up to the degree that intrinsic environmental values have to be safeguarded for future needs, the latter being point of many misunderstandings"

We like to thank our colleagues Yasmara Pourrier, Marjolein Marquez, Desiree Helder, and Marlon Faarup at the Central Bureau of Statistics Aruba for their general comments on the manuscript

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Towards a balance between socioeconomic and environmental developments in Aruba

This paper is an introduction to a series that describes spatial developments in the Aruban landscape. The aim is to provide information about the environmental issues that we face on our road to sustainability. The condition of the landscape is important as it plays a role as intermediator of environmental influences.

The aim is to review relevant information and make a first step in the establishment of an information database that includes a multiversity of data and relationships that matter to the interplay between the society, economy and the environment.

The series of papers does not pretend to provide a complete description of the spatial developments in the landscape in Aruba, but merely details some of the issues that appear relevant at present.

The scope for a landscape series

International programs developed by the EU and UN urge local administrations to prevent a further breakdown of environmental assets, while international bodies like the Intergovernmental Panel on Climate Change (IPCC[1]) make assessments and advise for instance on climate change.

It is an accepted view that global climate is changing and that, entangled in our way of living, there is harm to the environment that is to bounce back and bring immense costs to the overall economy and our well-being (IPCC, 2007) (World Economic Forum, 2016).

The General Assembly of the United Nations, aware of the incapacity of separate states to counteract these developments, proclaimed a set of Principles to serve as a guideline to local governments (RIO20+, 1992). The recommendations urge States, key sectors in society, and the population to take the health and integrity of the earth's ecosystem serious, and attempt to achieve sustainable development with environmental protection as an integral part of the development process (*RIO20+, Principle 4*).

Environmental bodies like the IUCN also advocate an integrative and global approach to safeguard for instance the landscapes and its biodiversity. Local cooperation and information gathering is critical to find a common base for support and to specify the allocation of time and money from international programs.

Recently, the Aruban government made the commitment to put efforts in innovation, energy-efficiency and sustainable actions (Aruba, 2011)[2] [3]. The prime challenge is to become less dependent from the import of oil-based fuels, given that the production of energy and drinking water depends heavily on the import of these fuels. Local initiatives such as a 'smart community' project and the 'solar panel roofing' at the airport are initiatives that propel further public interest. To help implement prevention, control, incentive and disciplinary measures, sustainability also requires the organization of information exchange structures and the continual monitoring of events (Aruba, 2013).

Information from land use and resource exploitation serves an important instrument to gain perspective of the changes in the environment (EEA, 2011). Globally, Aruba plays an insignificant role in the environmental human footprint but at the local and regional level the impacts on the environment do count. Aruba's natural scenery not just serves intrinsic environmental values but is highly valued by the (international) society and is recognized as a prime asset by the tourism industry (Murphy, 2011). A number of local trends cause concern, such as for instance the fragmentation and loss in habitats and biodiversity, the eutrophication of marine waters and the contamination of land surface areas[4]

The topics we cover in this series

The landscape has a strong historical and geological component, but the landscape also reflects the choices made when striving for prosperity. To improve our understanding we summarize information from different sources and describe the historic developments in Aruba from the time after colonial discovery in *Landscape series no. 2*: "*The history of resource exploitation in Aruba*". Also, we summarize information about the geological origin and geomorphology in *Landscape series no. 3*: "*A Review of Geology, Climate and Hydrology in Aruba*". The third paper in *Landscape series no. 4*: "*The suburbanization of the Aruban Landscape", provides* more detail on the relationship between geology and the extent of agriculture in early 20th century.

The current spatial developments follow each other in rapid pace and although there are still wildered spaces left, a suburban progression is recognizable. Already, we see a trend from the typical low-floor residential building towards two-storey accommodations. We describe these trends in separate papers and cover the issues of suburban developments also in *Landscape series no. 4*: "*The suburbanization of the Aruban landscape*" and, the changes in household accommodation and in the way we live in *Landscape series no. 5*: "*Housing and accommodation in recent decades in Aruba*".

In a final paper we cover some events that reflect a disharmony in the socio-environmental relationship. The pressure from the human footprint on the environment is reflected in the household concerns that we highlight in high spatial detail in *Landscape series no. 6*: "*Conflicts between the Economy and the Landscape in Aruba*".

[1] http://www.ipcc.ch
[2] Green Gateway: Economic vision and policy Aruba 2011-2013
[3] Binden, Bouwen en Bestendigen. Regeerprogramma 2013-2017

[4] We refer to International reports from [www.birdlife.org], [www.cepal.org], [www.ec.europa.eu], [www.dcnanature.org], [www.cepf.net], as well as local/regional studies and reports [(Bak, 1987), (Gast, Reef Care Curaçao Contribution no. 5: Nutrient Pollution in Coral Reef Waters, 1998), (Haapkylä, Ramade, & Salvat, 2007), (Baker, Glynn, & Riegl, 2008), (Del Nevo, 2008), (Lapointe & Mallin, 2011), (van Buurt & Debrot, 2012), (van der Burg, de Freitas, Debrot, & Lotz, 2012)].

Alert levels

To give some guidance, we examine the main global actors of present day environmental threats and evaluate whether they deserve local prioritization as well.

A review of the most urgent environmental threats of our time is put against a scale of pressure (Foley, 2010). International studies show that *Climate Change* due to elevated levels of predominantly CO_2 concentrations in our atmosphere, *Loss in Biodiversity* and the *Overflow of Nitrogen and Phosphor* in our atmosphere, land and oceans have already crossed the outer boundaries of what is thought to be safe. These processes thus deserve our highest local priority and attention (McKibben, 2010).

In Table 1 we check marked the nine major global threats in order of estimated local significance[4] in Aruba. Such local prioritization is tentative as there are only few local studies to support the prominence of the processes involved. We will discuss these local processes next in more detail.

1. Biodiversity loss	✓✓✓
2. Land use	✓✓✓
3. Freshwater use	✓
4. Stratospheric ozone depletion	✓
5. Nitrogen and phosphorus overflow	✓✓
6. Aerosol Particle concentrations	✓
7. Ocean acidification	✓
8. Chemical pollution	✓✓
9. Climate change	✓

Table 1 In total nine key environmental processes have been acknowledged globally that deserve local attention. These nine processes are based on research conducted by an international group of renowned scientists (ScAm, 2010).

Although *Climate Change* incorporates a major global problem, its local role of significance to environmental processes may be limited. Nevertheless, to comply with the international community, *Climate Change* is to be considered a topic that deserves high local priority as well. Problems like the *loss in Biodiversity* and *Nitrogen and Phosphor overflow* however do pose a direct threat to the local Aruban environment. We will discuss what above processes may entail for the local situation.

Climate Change

'Climate Change' in terms of a disturbed CO_2 balance comes with an interesting challenge in Aruba as, aside from the dependence on oil and the negative impact from the burning of fossil fuels (that causes the release of carbon dioxide in the atmosphere), there is detriment to the coral communities and unrestricted logging of trees that does not adhere to a restauration of the local carbon balance either (carbon sequestration takes place via the growth of coral communities and of vegetation). In the past, Aruba has been famous for harboring the largest oil refinery facility in the world (Ridderstaat, 2007) and with these oil refinery processes likely has been a major contributor to the release of greenhouse gasses. After the closure of the oil refinery, the island adds little to the global impact on climate change.

On the contrary, the local authority has taken the initiative to lower and even aim to completely exchange its oil dependence for more sustainable alternatives. Future actions in the environmental domain might be in line with this renewable energy strategy and advocate the use of *greenhouse-gas-friendly* products or implement local *reforestation programs*.

Loss in Biodiversity

With regard to the '*Loss in Biodiversity*', the ongoing residential and economic development in Aruba is responsible for a general loss in critical natural habitat, species and communities. However, while on the one hand such development seems to aggravate an overall loss in species, in particular to those species that are considered keystone species that help maintain the food webs of local terrestrial or marine ecosystem (Barendsen, et al., 2008), other species' abundance and composition may benefit from a shift in available types of food or the protection within the realms of human inhabited areas against wild predators such as from the Boa *constrictor*. In particular, the so-called culture-follower species, such as some birds are abundant near human inhabitation (Derix et al, 2011).

In regard to habitat degradation, the spatial extent of human agricultural presence a century ago is actually similar to the extent of economic development today (Derix, 2016d). The loss in critical land-based natural habitat, that is so evident today, mainly concerns the wildered agricultural terrains (locally referred to as 'Mondi') that exist for less than a century during which time of course nature may well have been at the brink of reestablishment. In particular the species that are characterized by their historical links to the Aruban culture are under the influence of the dramatic changes in the landscape.

Nevertheless, as elsewhere (Mcdonald, Kareivab, & Forman, 2008) it is perceivable in Aruba as well, that with the changes in the landscape there is a critical *loss in biodiversity* and *in habitat* albeit that only sparse information is available about species presence or abundance in the more distant past. Whereas newcomer species seem more abundant now than ever before (Derix et al, 2011), other often endemic species shift towards the edge of their existence and some have become extinct already (Barendsen, et al., 2008). Loss in food and nesting sites, competition by invasive species, caging and even predation by cats, dogs and the Boa *constrictor* (including by humans) all is part of the changing natural environmental setting and exemplifies the complexity of the problems that local species (animals as well as plants) face.

Network of corridors between habitats

There is a necessity to strengthen the robustness of remaining local ecosystems. Still economic developments pose a direct threat to the few remaining patches of mangrove forests or coral reefs along the coast, whereas mangrove and coral reef habitats can be considered the most threatened ecosystems in Aruba. We observe such situation on land as well, as remaining patches of (relatively) undisturbed ecosystems have become insufficient in size to serve as suitable habitat for the species survival unless we find a way to interconnect these areas and create a *network of corridors* (on land and at sea) that enable wildlife to disperse or find shelter and food.

The establishment of a large infrastructure of ecological corridors[5] can be an instrument to preserve biodiversity within the expansion of socioeconomic developments.

Overflow of Nitrogen and Phosphor

The potential *'Overflow of Nitrogen and Phosphor'* has received little local attention yet but might be significant in regard to the small island setting and the high population density (Gast, 1998) (Howarth, et al., 2000). It will be interesting to investigate the level of dissipation or binding by nutrients (and contaminants) to, for instance, the calcareous limestone soils and investigate in what degree they disperse with the ground water and rainwater runoff and may have a direct effect on the coastal marine ecosystems. Coastal residential sewage and fertilizers (amongst other sources) may certainly aggravate nitrogen levels and may even overthrow the soil binding capacity. Interesting to note is the importance of irrigation fields and areas like Plas Bubali to sequester free N compounds from treated wastewater before these can reach the sea (Buurt, 2008).

Land use

In Aruba, like elsewhere, societal, economic and environmental interests compete for available space and there is a *historic* and even a *geological component* embedded that defines our current opportunities and challenges to attain sustainability.

Housing, infrastructure and economic expansion have created, besides the loss in natural habitats, a landscape with environmental issues such as waste, litter, pollution, erosion, noise and other sources of human disturbance.

Aruba has a relatively high population density (ca. 602 persons/km^2 in 2014) with limited backcountry left, and aside from the protected National Parke area, there is reason for concern about the quality of the remaining landscape. In recent decades the population and new construction for housing increased consistently (Derix, 2016d) aggravating the human footprint in Aruba.

Waste, contamination and nutrient enrichment

In Aruba, '*Land use'* is likely described together with '*Ocean Acidification'* and '*Chemical Pollution'* (processes 7 and 8 in Table 1). For instance, on a relatively small surface area of about 180 km^2, there is an accumulation of waste from all imported products and goods produced by more than 100.000 inhabitants and approx. 1.7 million visitors per year in 2013 (almost 1 million stayover visitors, equal to 7.2 million visitor overnight stays, and almost 700,000 Cruise Passengers) (CBS Aruba, 2014). Obviously the goal to process and dispose such amount of waste sustainably is a challenge for the society and for the environment. Until recently litter and waste accumulated in one giant open waste dump directly bordering the sea, but last year the situation has improved considerably. A modern large waste gasification plant is designed to incinerate all types of waste while the gaseous residuals are meant to serve as an alternative fuel source for the water production plant nearby. Not yet accommodated however is the *liquid disposal* of nutrients and contaminants (including those from coastal cesspools) that locally leak into our soils and waters. The prolonged contamination of soils (in particular along the coast on the calcareous permeable limestone plateaus) and the leaking of nutrients into the ground- and coastal waters point toward a difficult problem that threatens the quality of coastal waters to sustain a healthy coral reef and mangrove ecosystem. We like to elucidate some of these processes a little further.

Clear coastal waters, white sandy beaches and a rich coral reef ecosystem exist as part of a wider healthy ecosystem that developed under local geological and climate conditions. Residential and economic activities however induce an environmental change that manifests not just on land, but also in surrounding waters, such as an increase in litter and pollution but also by disturbance and detriment to the coral communities along the coast (Chabanet, et al., 2005) (Goreau & Thacker, 1994) (UNEP, 2003) (OSPAR, 2010). The island setting is small and characterizes a low-level nutrient environment and a high nutrient recycling adaptation, i.e. local ecosystems have evolved to deal with an incidental abundance of nutrients to incorporate into the food web very efficiently. However, even robust systems are susceptible to an unremitting rate of nutrient enrichment and contamination and may shift away from their stable state. The current rate of change appears to overthrow the local ecosystems' resilience (M.Nystrdm, Folke, & Moberg, 2000).

An assessment of subterranean hydro chemical processes as well as processes on land is relevant to gain proper insight in the changes at sea and along the coast.

The example shows a reality of the complexity of processes that underlie specific themes. An environmental issue is most often multifaceted and requires policy and action at different levels and disciplines. The idea behind this '*series on the landscape'* is to inform about this complexity and thus encourage policymakers to define budgeted goals in this area.

Safe marine waters

Not covered in this series, but an issue worth mentioning, is the threat from accidental pollution of the Aruban marine environment with potential harm to the tourism economy, caused by large vessels that pass or anchor within Aruban territorial waters at less than 13 km off the southwest coast[6]. The sea surrounding Aruba is an area of intense marine traffic[7] and Aruban waters are still considered a safe haven in the region. An international corridor for shipping exists between Aruba and Venezuela beyond the distance of 3 miles (approx. 5.5 km) from the coasts[8]. Oil tankers often reside within Aruban territorial waters close to the coast as they await approval to enter Aruban transshipment piers, reside under maintenance, or, stay purposely in Aruban waters (foreign vessels) to await final destination. Local authorities may enact legislation when vessels enter the 3 mile zone, but, even outside this zone, intense traffic and anchoring oil tankers in general pose a potential risk to the Aruban coastal ecosystems. Information about incidences of oil pollution in our near coastal waters is not yet collected systematically.

[5] http://www.sicirec.org/definitions/corridors

[6] www.defensie.nl Topic: maritime boundaries of the Caribbean

[7] www.marinetraffic.com

[8] Border Treaty between the Kingdom of the Netherlands and the Republic of Venezuela (Trb. 1978, 61; 1979, 11)

Previous assessments

On several occasions there have been environmental studies focused on taking inventory, installing monitoring processes, building a system of environmental indices or implementing information exchange structures (Hengst & Rehorst, 1995) (Belle, 2001) (A.J. Schilstra and J. van der Perk, 2001) (Perk, 2003). These studies were planned in a broader scheme of environmental assessments together with respectively the University of Nijmegen and the University of Groningen in the Netherlands, but the initiative remained without follow-up. It proved to be difficult to recover the reports of these studies but the underlying data were lost and with it some important baseline data. Occurrences like these show the weakness of information exchange and stress the importance of storing and sharing data and reports in an organized network of databases and libraries.

After the disintegration of the Department VROM[9] in 2002, the Department of Public Works (DOW), Department of Infrastructure and Planning (DIP), the Cadaster (DLV), and the Institute for environmental monitoring (IVM) shared the responsibility of environmental matters for over a decade. With the launch of the section of Environmental Statistics in 2012, the Central Bureau of Statistics made a first start to gather available environmental information from different disciplines and stakeholders. Thematically, this information is disseminated in a series of publications on energy, traffic, biodiversity and landscape (www.cbs.aw/environment). In 2013, a more dedicated authority for environmental matters the Department of Nature and Environment (DNM) was established to advocate the role of nature in society.

In 2008, a Spatial Development Plan (ROP, 2009) was completed to streamline the spatial extent of societal growth and economic change and be able to acknowledge local environmental values. The plan developed by the Department of Spatial Development and Infrastructure (DIP) is considered a milestone in the planning of sustainable growth with inherent environmental protection, although not all environmental issues could adequately be covered. But it is an important first step in spatial planning and the incorporation of as well urban as environmental interesting areas. The plan depicts regions for nature restoration, housing projects, economic expansion, agricultural development, and infrastructure and so on. Embedded by deliberate rules and regulations (ROPV) the plan was meant to act as a guideline for spatial development while it still remained adaptable to changes in the definitions of local areas. The formalization into a series of binding rules and regulations that would integrate juridical support and measures of control, however proved to be difficult (Arends, 2009). The plan in optima forma is meant to provide sufficient juridical stronghold to maintain future spatial developments in Aruba in line with nature conservation efforts and sustainable growth of economic and social well-being.

9 VROM (Directie Volksgezondheid, Ruimtelijke Ontwikkeling en Milieu). Directorate of Health, Spatial Development and Environment.

Meanwhile, from within the tourism industry concern was ventilated about the future of the tourism industry in perspective of a worsening of the condition of the landscape and local environment. In 2011, a '*Forum for the Future of Tourism in Aruba'*[10] concluded on the basis of specialists' reports that (amongst other factors) *the restoration of environmental forces and pristine natural Aruban settings* is of major concern to be able to compete internationally for tourist visitation (Murphy, 2011). There was realization that current *land degradation had gone too far* and that the *'pristine' Aruban countryside* was losing its tourist attractiveness and competiveness with other islands in the region. The landscape and natural environment was not simply an asset that would be always available, but required consideration and maintenance. It was necessary to engage more than simply to keep the environmental impact in check or explore the local carrying capacity of available land to capitalize further growth.

However, it is no easy task to uphold an image of a typical Aruban landscape or pristine nature in the complex of interrelationships between societal and economic interests. Ecological restoration and sustainability is more than a simple make-over of the areas involved and includes a change in consumption patterns, land-use management, public awareness programs, environmental monitoring, research and legislation, and an information infrastructure.

The use of GIS[11] to analyse environmental data in high spatial detail

A *system of environmental indices* has often been called for to help asses and monitor ongoing environmental processes. Similarly, at the interface between economy and environment *ecosystem accounting* and *environmental valuation* (of local nature resources) have been proposed to offer means to better understand the value of the local environment in terms of embedded economic costs and benefits.

To develop such assessment and help identify alert levels and indicators requires an open and dedicated local and regional system of information exchange. The interest for cooperation in data gathering and the support from research is of course imminent[12]. Momentarily, the implementation of an integrated system of socioeconomic and environmental indices is not feasible as a system for environmental information exchange is not yet installed. Also, we are far away from defining alert levels and local tipping zones (or local threshold values). But, with the information available we may already recognize and define prime local '*alert types'* similar to those as mentioned in Table 1 at the global level.

10 http://arubatsa.com/atsa-tourism-leaders-review-factors-affecting-tourism/

11 A GIS (Geographic Information System) is a computer-based tool that enables the linking of information from many different fields on the basis of a common geographic component. Layers with information from for instance, socioeconomic, environmental and topographic surveys are brought together on a common spatial scale. Linked in this manner, the GIS system provides additional information and opportunities for research.

12 From: Beyond GDP_EU-2009

In its role of carrier of information the section of Environmental Statistics of the Central Bureau of Statistics in Aruba is dedicated to improve however the dissemination of environmental information. The aim is to build and enhance an integrated structure of monitoring systems to collect information from stakeholders and own research in order to better serve requests from policy makers and other stakeholders.

The current landscape series accounts the status of information in relation to landscape characteristics and emphasizes the lack of information on several subjects.

In order to be able to construct a system of environmental indices or set up a system of energy, land-use or water accounts, for instance, more efficient monitoring systems, data collection and harmonization is necessary.

Environmental information is strongly related to a given time and place, so it is important for the better understanding of underlying processes to acknowledge the specific circumstances during data collection and analysis. For example, we may use satellite images to determine the changes in vegetation growth or land coverage, but we have to compare images from similar seasonal conditions. GIS (Geographical Information System) technology is an essential tool to enhance the quality and productivity of environmental studies. For this reason, many environment statistical agencies worldwide are intertwined with a GIS department.

The spatial embedding of data

Spatial embedding of data allows information from different fields to become linked by a common geographical component and to describe issues at the interface of society, economy and the environment from a multidimensional perspective. We have initiated the following approaches to improve the support of environmental data gathering, exchange and dissemination:

The national Grid System (ARUGRID-System)

Environmental data cannot always easily be linked to socioeconomic data because both fields are to some extent spatially separated. Also, environmental data often refer to concentrations or areas without a strict border. A common solution is to disseminate socio-environmental data on the basis of a reference raster of grids. Areas are split in small squares and different data can be presented similarly in an aggregated manner. Modern GIS techniques offer a wide range of possibilities to analyze spatially distributed environmental and socio-economic data, but the use of grids is easily understood and directly convertible to/from other analysis software.

The EU, in cooperation with the EEA (European Environmental Administration) encourages the use of Grid reference systems to their federated states and are currently working on a proposal for an ISO standard: "EEE recommends the use of multipurpose ETRS89 Lambert Azimuthal Equal Area 52N 10th grid.

The European Environmental Administration has developed a tool (EEA Fishnet Tool v1) to create a grid using ESRI ARCGIS software. With the tool one can create a polygon or line 'shape file according to the EEA standards of an ETRS-LAEA grid.

In Aruba, we cannot use this same grid because we are too far to the West, but the department of environmental statistics already used a similar projection of geographical data as in the EU throughout its earlier analysis. At present, there is no *official Grid Standard* for Aruba, but the '*Aruba Grid System – ARUGRID* (prep, 2016g) may serve this purpose.

In a number of publications, the ARUGRID System has already been used to disseminate some small sets of environmentally oriented data obtained from the 2010 Population and Housing Census (Derix, 2013a) (Derix, 2013b) and the Aruban Bird Count (Derix et al, 2011). In this series on the Aruban landscape, we will continue to disseminate our results in use of the ARUGRID System.

The *Central Bureau of Statistics* of Aruba (CBS) proposed a number of additional initiatives to ease data collection and data exchange and to improve the quality of up to date relevant information (Derix, Opportunities and Challenges in Environmental Statistics in Aruba, 2014), such as will be necessary to complete the monitoring system layout.

The National GIS Platform

In cooperation with the Departments DLV (Cadaster), DIP (Infrastructure and Planning) and the DOW (Public Works) (Derix, 2009), a plan is proposed to establish a National Spatial Infrastructure, the "*National GIS*" project. GIS is to become the main instrument of collaboration to create, store and share relevant information on the basis of the spatial component. The maintenance of information and the interchange between participants is well-supported in *a network of GIS databases*. The original proposal (Derix, 2009) to enhance collaboration and establish a national GIS infrastructure is conform modern ideas of information exchange. Similar enhancements of the information infrastructure are in preparation in other Caribbean islands as well (URISA, 2014). Consequently, new opportunities arise to connect and build on knowledge transfer on the international scale as well.

The use of smart imagery interpretation technologies

Aside from the infrastructure of cooperation, much of the information we need to establish is missing or incomplete. As history learns, in a small island community setting it is difficult to monitor, collect, aggregate, and disseminate all the relevant information by own means and also keep an up to date and complete database as well over the years. Information gathering and integration requires more time and resources than are available and high accuracy in terms of data consistency and reliability. One way to meet these requirements is the use of *smart imagery interpretation* technologies. The idea however requires external funding and support.

The *semi-automatic interpretation and digitalization of satellite based landscape imagery* would deliver very relevant local data that might otherwise not be collected. This initiative from the CBS was integrated into an EU funding proposal, headed by Netherlands Organization for applied scientific research TNO and its Caribbean Branch Office CBOT in Aruba, that incorporated the idea into a study on *land-based rainwater runoff and groundwater pollution on coral reef ecosystems* (WACUP, 2014). The final setting included a partnership between 25 international research institutes in Europe. Aruba would profit not only by investigation of the islands' rainwater run-off processes and its effect on the coral reef ecosystems, but equally important, would install along the way an effective information exchange instrumentation. Leaning on the expertise and support from international research institutes, this project and the planned National GIS setup would fit well the interest of local authorities.

Landscape series: Summary and Conclusions

In ***Landscape series no. 2*: *"The history of resource exploitation in Aruba*"** (Derix, 2016b) we created a time window and a short overview of the exploitation of resources and the impact thereof on the landscape. Next, we will briefly summarize its contents; however, for more detail and readings we refer to the aforementioned paper.

Available resources often propelled the economy but sometimes only made it possible to cope with the harsh conditions of local subsistence. Periods of grazing, deforestation, cultivation and mining subsequently had their impact on the face of the landscape while the newly created conditions triggered new opportunities for wildlife and for man. In essence this is still true for today's situation, be it that the fast pace at which new conditions occur infringes with the time left to preserve the remaining nature.

In recent decades there has hardly been any environment-oriented monitoring program, so we do not know exactly the distribution of local species and habitat requirements. Without doubt, there has been a notable change in the Aruban landscape by the defragmentation and loss of species' habitat due to new infrastructure and construction. This is not the first time, however, that the Aruban landscape underwent drastic changes.

From late 16th by the Spanish and mid-17th up into late 19th century by the Dutch, the red dye-wood Haematoxylon *brasiletto*[13] was a solid source for wood (dye) export from Aruba to Europe. The harvest of these and several other species of woods from Aruba characterized a long history of deforestation. The local dye-wood is repeatedly named Brazilwood but todays' scientists prefer to use the name *Peachwood* (Cardon, 2007) to keep from confusion with the so-called *true Brazilwood,* Caesalpina *echinata,* originating from Brazil. Unfortunately, we miss information about the coverage and extent of dye-wood habitats in the distant past. The favored habitat in Aruba may have been on the limestone terraces along the coast as there is a preference for calcareous soils but specific information is lacking. Today, only remnant trees of Haematoxylon *brasiletto* remain in Aruba on a few locations.

The long-term harvest of dyewood (and other woods) and the grazing by large herds opened the face of the Aruban landscape and created exactly the right conditions for further development with Aloe and mixed agriculture. At the end of 19th century, all along the coast, most limestone terraces were readily cultivated with Aloe. After wood became economically unimportant for export, the harvest of woods continued, either for construction, as local firewood or as firewood for the lime kilns. Woods were cut in Aruba up into the 20th century and old trees actually are remorselessly cut even today.

Current economic and residential growth created a suburban landscape that in spatial extent is about the same as the agricultural landscape at the start of 20th century (Derix, 2016d).

We made a comparison between the land in use now and at the beginning of 20th century, exactly one century ago. Wildlife was already in retreat by the destruction in habitat, by hunting, fertilization and chemical pollution. Its use for agriculture and later also for the oil industry intensified the draining of aquifers and groundwater[14] and may have intensified a salinization of the groundwater as well. Today, in the inhabited areas the opposite may be true, as waste water and irrigation constantly leak into the soils. Residences offer rich garden systems with plenty of water, shelter and food but the soil and groundwater enrichment is likely to influence the food chain and favor some species above others (Zhang, 2015) (Mcdonald, Kareivab, & Forman, 2008). More so than in the past, international trade and mobility introduces exotic species that in the newly disturbed environments compete successfully with the local endemics.

In 1950, the Dutch zoologist Freylinck stressed in an inventory of local species in Aruba (Freylinck, 1950) the extinction of several bird species, amongst which the Aruban Green Parrot (Amazona *barbarensis*) and the Ala Blanco (Columba *corensis*). Also, he noted, that other species had become rare. The landscape he describes was very dry and almost without any vegetation. The land in the west and the northeast he even depicted as a stony desert.

Today, another number of species have become rare whereas some have become more abundant. The key stone species[15] generally have difficulty to survive (Mcdonald, Kareivab, & Forman, 2008). For instance, large flocks of the Caribbean parakeet (Aratinga *pertinax* arubensis) have 'always' been a common sight in the past, but nowadays the parakeet is seen mostly in pairs or in small flocks of three to four (Derix et al, 2011). It may be that this is an adaptation to todays' more dispersed allocation of food resources. The majority of the large orchards with fruit trees and large crop fields have been fragmented or lost, leaving the birds without the local abundancy of food

[13] Note: Haematoxylum *brasiletto* is very rich in *brazilin* (Dapson & Bain, 2015). Brazilin is obtained from the heartwood of the tree and acts as precursor to the red colored dye *brazilein* when it is oxidized. In Europe, the red dye colorant was welcomed in early colonial times to replace more expensive colorants from the East. But little is known about the many different other uses of the colorless component *brazilin*. Haematoxylum *brasiletto* is known for its uses in textile and histological staining (Cardon, 2007) but its extracts are also used for medicinal treatment of diabetes, blood pressure and gastrointestinal problems. Brazilin is also known in pharmacology for its antibacterial properties and use as antibiotics, antiobesity, antioxidant and antitumor remedy as for many other purposes (Dapson & Bain, 2015). It might be worth to explore whether a reforestation with the typical local dye-wood might offer opportunities for export as well.

[14] The pumping of subterranean fresh water sources was necessary for the oil refining process (Ridderstaat, 2007).

[15] A keystone species is a species that plays a major role in the food web and local ecosystem

sources. We do not observe many small flocks either, so it is reasonable to assume that besides the change in diet and food availability the parakeets do actually have difficulty to survive for other reasons as well. Influences such as the loss of social nesting and social sleeping sites or the predation by the Boa *constrictor* may also contribute to their decline. Moreover, still today, young birds are caged and old nesting trees are cut as they may harbor termite nests (parakeets typically build their nest in the tree-hollow nests of termites) or because the land is cleared for construction (which is often not the case after all).

In ***Landscape series no. 3***: **"*A review of Geology, Climate and Hydrology*"** (Derix, 2016c) we bring perspective to current environmental developments in terms of geological (Busonjé, 1974) (Beets, Metten, & Hoogendoorn, 1996) and (paleo) climate conditions (Hodell, et al., 1991). We place in a simplified manner the geological history of current landforms in a historical perspective and describe its effects on the current hydrology and topology of the landscape. This information is relevant for the understanding of the current environmental issues in the local settings.
We exemplify the strong relationship between geology and landscape and interpret as a case study the geological information from Beets (1996) and Busonjé (1974) with the information from the topological Werbata-Jonckheer map that describes the situation in 1909-1911 (Werbata, 1913). We refer to Krogt (2006) for information about the maps from Werbata (terrain surveying W.A. Jonckheer). The relation between geology and early land use is substantial for modern spatial developments, as it determined the layout for todays' construction, surface- and groundwater management, rainwater runoff and exposure to flooding that in turn relates to eutrophication and contamination of local soils and marine waters. Currently an inventory is being made of the extent of agricultural activities that will make it possible to calculate an index of land cover. For further reading, we refer to the paper.

In ***Landscape series no. 4***: **"*The suburbanization of the Aruban landscape*"** (Derix, 2016d) we detail the subsequent shifts in economic interest in the different regions in Aruba. The growing population brings along a wave of construction that started in the early 20th century in the south-east (influenced by the need for workers in the oil refinery) and gradually displaced towards the north-west (influenced by the booming tourism industry). Early land use and infrastructure however has set the layout for today's traffic congestion and problems in infrastructure and to some degree still hampers the spatial developments. The shift in economic activity towards the north-west has created a hotspot for business activities and land development projects. Many of the employees, however, cross the full length of the island on a daily basis for their trip to work. The road infrastructure is not designed to cope with so much traffic, causing traffic jams and harm to the environment by fuel use, car exhaust, and the construction of new roads. The construction and expansion of houses has shown a declining trend, however the construction of new apartments has increased. Interestingly, while total investment in new residential construction has dropped, the investment per square meter has risen. A change is evident in housing characteristics and in the way we live. For further reading, we refer to the paper

In ***Landscape series no. 5***: **"*Housing and accommodation in recent decades in Aruba*"** (Derix, 2016e) we analyzed the densifying pattern of residential construction, the changes in housing conditions and the use of construction materials. We observe a striking difference between the northern and southern region in Aruba in the use of air-conditioning systems. There is also a trend towards smaller houses with fewer rooms and smaller plots, but often with two or three floors and using different construction materials. For further reading, we refer to the paper

In ***Landscape series no. 6***: **"*Inconveniences in the home neighborhood in Aruba*"** (Derix, 2016f) we analyzed the distribution of household inconveniences to reveal aspects where the economy, society and environment fringe. Also we go into detail on the environmental hazards that lie hidden in our daily household consumption patterns. For instance, the daily disposal of solvents and liquid waste in the direct surroundings of our living environment comes with an accumulation of nutrients and contaminants and a long-term effect on the quality of soil and groundwater as well as surrounding marine waters and ecosystems. For further reading, we refer to the paper
We used the National Grid Reference System to describe at the finest spatial detail some of the related processes. We were able to define the areas that experience flooding after heavy rains and where 'air pollution', 'noise', 'dust', 'litter', 'stray dogs' or 'car wrecks' cause inconveniences in the neighborhood. The spatial analysis with GIS technology proved to be very relevant (despite the limited availability of GIS analytical tools in the ESRI ArcView version) to understanding the local dimensions of problems that have a social, economic and environmental component.

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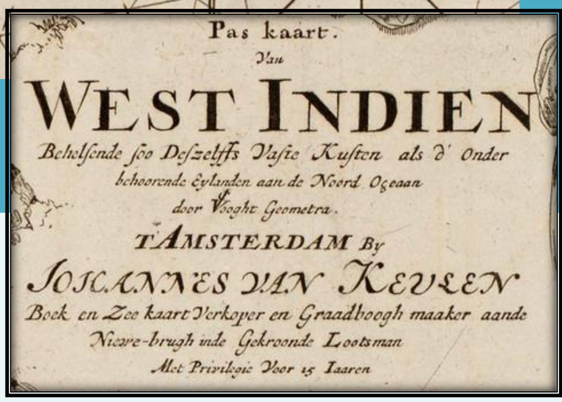
Landscape series: 2

The history of resource exploitation in Aruba



Fragments from an early maritime map from 1684 with reference of 'Isla Oruba'
by J. van Keulen (Publisher/Cartographer) and C. J. Vooght (Cartographer)
Source: Dutch Maritime Museum Amsterdam
In: www.geheugenvannederland.nl

The Aruban landscape has undergone many changes in time. This paper reviews aspects of its resource history and is part of the series: "Spatial Developments in the Aruban Landscape: A multidisciplinary GIS-based approach derived from geologic, historic, economic and housing information"

2016

Contents

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This paper is part of a series on the Aruban landscape. To bring perspective to current environmental threats and developments we review, in this paper, the history of resource utilization in Aruba. Good knowledge of present but also of past processes is vital to understanding the effects of urbanization and economic progress on land- and marine-ecosystems.

The history of resource exploitation

The architectural, cultural and political history of Aruba is quite well documented. In the context of this paper we like to recall some of the historic events that strongly relate to the utilization of local resources in the region and that indirectly had a lasting effect on the face of the landscape in Aruba. We review information from, amongst others, Hartog (1953), Versteeg and Ruiz (1995), Alofs and Dalhuisen (1997), Ridderstaat (2007) and Bakker and Klooster (2007) and follow a division into periods as used by the National Archaeological Museum Aruba (NAM, 1999).

Over time, the landscape and vegetation in Aruba changed due to fluctuations in geological and climatic conditions as well as due to the impact of human action. In Figure 1 (pp. 7) we present a schematic overview of the events in the Caribbean that help to understand the influences that Aruba faced during the colonial period and thereafter.

Preceramic Period
2500 BC – ca.1000

Over the years, the Archaeological Museum of Aruba has done extensive research on (pre) historic living in Aruba. Based on stone tool findings, mainland inhabitants are thought to have made occasional visits to the island as far back as 4500 BP[1] (2500 BC). Two cave burial sites and a number of remains of small Amerindian settlements have been discovered in the coastal areas on the limestone terraces. A few stone extraction sites windward in the hilly northeast coastal area are thought to date back from Preceramic Amerindians as well. The piles of shells and artifacts indicate that the Preceramic Amerindians had a mainly marine orientation and lived predominantly from fishery. The location of these settlements along the lower coastal regions is associated with the near availability of freshwater and the location of mangrove forests (the typical habitat for shellfish and other easy to catch marine life) (Versteeg & Ruiz, 1995). Shell midden sites may provide further clues to the daily lives of the natives and the biodiversity at the time but no related studies are known to us. Today mangrove forest can only be found in some inlets and the islets along the southwest coast predominantly.

A palynological study suggests that the landscape and vegetation had changed millennia ago. In older sediment layers proof is found that primordial Aruba likely was covered with a dry tropical forest (Nooren, 2008). Pollen records of a sediment core from Frenchman's Pass list fern spores and an abundance of pollen from the tree species Bursera *simaruba that* is recognized as an indicator species for disturbance[2]. What is more, charcoal deposits have been found as well in these layers. The occurrence of charcoal deposits and ferns and tree pollen within the otherwise Mangrove dominated peat layers, points towards disturbance and probably a more open landscape with deforestation near the lagoon during pre-Columbian times, thus long before the arrival of the Spanish colonialists (Nooren, 2008). The findings confirm the descriptions of slash/burn human activities in the preceramic period. New palynological studies may reveal interesting new facts about the vegetation and climatological circumstances in pre-Columbian time. Interesting to note is that at the Boca Prins lagoon in the northwest littoral zone, the occurrence of pollen from typical littoral Mangrove forests from up to the end of precolonial times switches completely towards pollen from more inland species. This suggests a large-scale erosion of soils in early colonial times, suggestive for a deforestation of woods (Nooren, 2008). A large-scale harvest of woods during Spanish and Dutch colonization follows from the details of early WIC journals (Müller, 1637) and is described in Teenstra (1936 and 1937) and in Hartog (1953).

Ceramic Period
ca 1000-1515

Quite a number of archeological sites have been characterized by the absence of the large heaps of shell-remains and instead are surrounded with an abundance of pottery artifacts (Versteeg & Ruiz, 1995). Accordingly, these sites document the Ceramic period in which already a considerable population of Amerindians inhabited Aruba. Three larger and two medium-sized villages have been discovered with permanent settlement. The majority of sites are located on the higher grounds that are more suited to the needs of agricultural activities at the time. According to the authors, there must have already been some influence on the landscape in terms of subsistence agriculture and deforestation by the Amerindians. This happened long before the Spanish arrived.

Spanish period
1515–1636

During the Spanish colonization, after the killing and deportation of the Caquetio Amerindians as slaves to Hispaniola in 1514 from Curacao (Deive, 1995) and later in 1514 from Aruba (Alofs, 2015), settlement in Aruba other than by Indian laborers, arrivers from the mainland, and a few Spanish settlers was not allowed by the Spanish Crown. In fact, there was not so much interest in the island by Spain other than for geostrategic reasons to secure the waters and trades off the mainland near the capital Coro and present-day Venezuela (Alofs & Dalhuisen, Geschiedenis van de Antillen : Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten, 1997).
Since the arrival of Spanish colonization and into the 17th century, the landscape in Aruba underwent fundamental changes from the cutting of woods and the grazing by free roaming herds that were introduced by the Spanish (NAM, 1999). The introduction of animal husbandry brought a shift in the ecology (and erosion) of the Aruban landscape. The exploitation of the landscape intensified after the Dutch took control in Curacao in 1634, i.e. not too long after the 12 years' Truce (1609-1621) and the recommencement of the Dutch resistance against the Spanish Crown (Teenstra, 1837).

[1] BP indicates Before Present in 1950.
[2] Reference cited in Nooren, 2008.

Early salt, wood, cattle and other resources

In 80 years of war, the Dutch had a lasting resistance against the occupation by the Spanish Crown (1568-1648). Despite this ongoing conflict with Spain, the economy of the Dutch Provinces grew. When the 12 years' Truce ended in 1621, the Dutch intensified their international trade and strengthened their presence in the Caribbean with the institutionalization of the *Dutch West Indian Company* (WIC).

The successful Dutch fishery in the late 16th and early 17th century required a steady supply of salt. Salt was crucial to preserve the dried fish, predominantly herring. Because of a Dynastic Union between Spain and Portugal, however, the Dutch had come into conflict with Portugal and lost their access to important salt resources. Even worse, the high quality Caribbean salt from St.Maarten had become a crucial commodity but this WIC stronghold was also soon lost to the Spanish. The Spanish marauding of the Dutch salt trade was part of the larger conflict and directly affected the expanding Dutch economy. At their turn, the Dutch seized an opportunity with the taking of control of Curacao in 1634 and immediately thereafter of Aruba and Bonaire (which conveniently offered high quality salt resources) (Curaçao Maritime Museum, 2016).

West-Indian period
1636–1792

In addition to salt, these islands offered another highly valued commodity, dyewood (Gehring & Schiltkamp, 2011). In Europe, only the rich could afford brightly colored cloths made with expensive Oriental dyes, but with the dyewood from the West the production of more affordable dyes to color cloth for the common became possible. While the Spanish had a strong harvest of high quality dyewood, referred to as Logwood, in the Campèche region in Mexico *(*Haematoxylon *campechianum),* the Dutch managed to secure their share in the dyewood industry and invade the Pernambuco region in Northern Brasil, where another dyewood (Caesalpina *echinata*) was harvested by the Portuguese. The high quality Pernambuco dyewood became known as Brazilwood[3]. Later, the wider region including Pernambuco got known as Brazil.

After one hundred years under Spanish rule, first WIC Commander/director Van Walbeeck intended to strengthen his military presence in the Caribbean and intensified the exploitation of the islands' resources. Local woods, such as *Stockvishout*[4] *and ironwood*[5] were harvested and exported to Europe. Van Walbeeck destined Curacao as the administration and military outpost, while its land was developed for agriculture. Bonaire was particularly suited for salt exploit and, like Curacao, had forests that could be harvested for wood. Aruba was the least promising for suitable resources and destined to raise livestock, such as cattle, goats, pigs, sheep and horses that could be left to roam freely. Interestingly, upon first arrival, Van Walbeeck describes Curacao as covered with forests. He notes that although the Spanish already had logged some quantities of 'Stockvishout', apparently there was easy regrowth and still plenty available (Teenstra, 1836).

Unfortunately, no detailed description of the landscape of Aruba of that time is available. So we have no knowledge how Aruba must have looked like when the Dutch first arrived. We do know that the Spanish had already released some herds in Aruba and that they harvested coppiced wood from present low forests (Versteeg and Ruiz, 1995, pp 60). During those Spanish years, Aruba remained in relative quiet isolation. This situation didn't change much during WIC I.

Later, when the WIC II gained control over the islands, Indians were given protection. Indians could attain a tax-free piece of land that they were allowed to cultivate in return for some services to the WIC (referenced in Hartog, 1953).

The logging of wood, in particular Stockvishout, continued over two hundred years, far into the 19th century, with the peak in export in the late 17th century. It was not before the piracy in the region settled down in the middle of the 18th century, when Aruba again became safe for inhabitation by settlers. Privileged settlers moved from Curacao and were allowed to run trade (with Europe and with the Guajira Peninsula in Northeast Colombia and the Venezuelan mainland) directly from the Aruban territory (Kelly, 2012).

At the end of the 18th century, during the years of the global trade crisis, the WIC II dissolved as it got into financial troubles. When, in 1792, the WIC lost the rights of rule in the region, Aruba came under rule of the '*Republic of the Seven United Netherlands'*. One year later, however, the Republic came into war with France and ten years later into war with England, so there was little means to protect the islands from the occasional raiding by rival ships. Opportunistically, the small and distant Aruba went under control by the flag that happened to anchor in the harbor. In the early 19th century, Aruba came twice under English control, from 1801-1803 and 1806-1816. After that time, Aruba was left in struggle as the English caused severe damage and had taken all the cattle and piles of stocked woods (Hartog, 1953). The new settlers from European

Colonial period
1792–19th

[3] Antillean dyewood [Haematoxylum *brasiletto*] from Aruba, Bonaire and Curacao was named by early Dutch as 'Stockvishout'. Alternative names such as 'Braziel', 'Brasia', 'Brasil, or 'Brazielhout' are practiced as well and translate to 'Brasilwood' or 'Brazilwood', but refer to a more common naming for red dyewoods based on the Latin name 'brasa' for ember, like the glowing coal or wood in a fireplace, in reference to the reddish color of the wood. Today, the English name 'Brazilwood' is reserved to refer to the famous Pernambuco wood ['Caesalpinia *echinata'*].

[4] Antillean dyewood 'Stockvishout' [Haematoxylon *brasiletto*] is listed in the Amsterdam tax inventory in 1667 (Brugmans, 1898) separate to dyewoods, such as 'Brazilienhout' and 'Campechi'. Also in the WIC journals, Stockvishout and Campeshi are categorized next to each other in a single ship log (Müller, 1637). Thus the names are probably not used alternatively for the same tree species. Interestingly, in an extract of the WIC ship log of the arrival of Van Walbeeck in Curacao, in 1634, already mention is made of the local dyewood named 'Stockvishout' (Teenstra, 1837). The name Stockvishout may be a reference to the common practice to dry fish, typically "kabeljauw" or Atlantic Cod (Gadus *morhua*) on a wooden frame of sticks. In Dutch a wooden stick translates to "stok" and the fish ("vis") thus dried may be named "Stokvis" or translated in older Dutch "Stokvisch" or "Stockvis". The question "Why the wood that was harvested by the Dutch was called 'Stockvishout' in reference to a practice to dry fish and not in reference to its actual use as a dye-wood?" remains yet unanswered, however.

[5] Ironwood (Guaiacum *officinales*) was mainly used for construction and was named after its hard and dense properties. The wood is locally called Wayaca and '*Pokhout'* in Dutch or 'Lignum *vitae'* in English, in reference to its medicinal qualities for the treatment of the *Great Pox disease* (in Dutch called '*Pokken'*).

origin depended on *small-scale agriculture, fishery* and the *herding* of *cattle,* like the Amerindians had done under Spanish and first WIC rule. The logging of wood continued while the trade with the South American mainland offered some additional economic income (Teenstra, 1837).

We mention some exploitations of resource in 19th century and onwards that had a substantial bearing on the landscape in more detail.

1820

Lime

In Aruba, similar to in Curacao, Mangrove forests along the coast were logged to construct commoners' houses and to fuel stoves and lime kilns (Versteeg & Ruiz, 1995). In the early 19th century, lime was a modest export commodity and locally used in construction, until well into the 20th century. *Limestone* is a sedimentary rock composed of *calcium carbonate* skeletal from marine coral that after burning (calcination) turns into a reactive product calcium oxide (*quicklime*) and carbon dioxide. When neutralized with water it becomes *slaked lime*. Lime has many usages.

1824

Gold

Gold was incidentally found in 1824. Local farmers and fisherman all went to search for the alluvial gold, but the actual digging in the quartz veins of diorite rocks became a prominent economic activity only some years later. Several consecutive attempts have been undertaken under different concession ownerships to make gold exploitation profitable but most failed (Ridderstaat, 2007).
Initially, gold was extracted with little invasive techniques but at the turn of the century a new technique was introduced to distract the gold from the quartz. The process of suspending the crushed ore in a cyanide solution eased the extraction whereas the load to the environment was then yet little understood (Morin & Hutt, 1998).
Quartz was transported with donkeys to Balashi and along a small tramline from the Miralamar mine. Between the gold factory in Bushiribana and Oranjestad a road was constructed with the intention to ease transportation of the heavy machinery that was required for the gold extraction. Also for this purpose, a new pier was built in Oranjestad (Ridderstaat, 2007). The exploitation of gold lasted about a century, into World War I.

1840

Aloe

Initiatives to stimulate settlement and agricultural production inland started in about 1830 in the area of Canashito and in 1852 in what is now called St. Cruz and Savaneta. Crop farming and fruit- and seed bearing trees were successful on terrains that were about 2 ha in size.
In the meantime, Aloe (Aloe *barbadensis* or Aloe *vera*) was introduced (1840) on the terrains of former cochineal breeding (Ridderstaat, 2007) and soon became the main product of export in the late 19th century. *Aloe cultivation was* situated predominantly in the southwest coastal areas, and in particular, on the limestone terraces[6]. The map that was made by Werbata–Jonckheer in the period 1909-1911 provides a detailed account of the topography and extent of the Aloe fields in the Aruban countryside (Werbata, 1913).
It is worth to mention that in the first half of 19th century and onwards a number of efforts had been made to improve subsistence level and gain extra income from the export or the exploitation or alternative more drought-resistant cultivars.

The breeding of *Cochineal mites* (Dactylopius *coccus*) on Opuntia specs in Aruba in 1831 was such a government initiative. The successful production of a carmine-red dye, from the contents of the dried and crushed mites, had existed for thousands of years already in other parts of the world. But the production was discontinued in Aruba in 1869 as the export suffered from direct competition and the production of artificial colors elsewhere (Ridderstaat, 2007).
Ridderstaat (2007) also recollects the initiative to export *seedpods from Divi-Divi trees* (Caesalpinia *coriaria*) for the European tanning industry that lasted for almost a century (1840-1935). The harvest of these pods was mostly a family undertaking and meant some extra income. But the export has never been substantial.

Phosphate 1874

During the last half of the gold digging era, the profits from gold were surpassed by the much more profitable *phosphate* production (1879-1914). Phosphatized limestone layers from guano droppings had been found at the southern coastal strip in Aruba. The deposits were from large colonies of seafowl that foraged in the surrounding rich waters during late Pleistocene some 1.8 Mio years ago (Stienstra, 1985). A pier in the bay of San Nicolas was constructed to import the machinery for its exploitation. Also a small rail track was built to transport the phosphate from the mine in Seroe Colorado to the harbor (Ridderstaat, 2007). Similar to the decline of gold extraction and Aloe production at about the start of World War I (1915) the production of Aruban phosphate was outcompeted by more profitable production elsewhere in the world (i.e. an easier supply of raw materials during the war) and the competition from the higher wages in the oil industry (Ridderstaat, 2007).

At the 1883 World Trade exhibition in Amsterdam (Eeden, 1884), hardwoods like *Pokhout* [Guaiacum *officinales*], *Kibrahacha* [Bignonia *stans*] and *Divi-Divi* [Caesalpinia *coriaria*] were slightly represented and no account was made of *Stockvishout* [Haematoxylum *brasiletto*] at all. The logging of dyewood had already been slow since the mid-1800 and probably had ceased completely in 1883. There was a display of Aruban handcrafting and twining basketry for which *Mangrove twines and roots* were used.
After over three hundred years of grazing the landscape and harvest of dyewood and other local hardwoods, the landscape in Aruba will have changed dramatically at the turn of the 19th into the 20th century. The landscape was ready for the next phase in resource exploitation.

Agriculture 1911

In the early 20th century, agricultural activities already covered nearly the whole central part in Aruba, i.e. most of the quartz-diorite based Batholith landscape (De Busonjé, 1974). In another paper of this series on the Aruban Landscape (Derix, 2016d) we describe the very detailed

[6] Based on a preference for calcareous soils it is quite probable that the dye-woods [Haematoxylum *brasiletto*] that had been harvested in the decennia before may have covered the limestone terraces in particular.

topological map from that time, the Werbata map[7], in more detail (Werbata, 1913). 'Forests', however, could not be discerned on the map. It is obvious that after the continuing harvest of woods for export, construction and to fuel the furnaces of the lime kilns and phosphate ovens, most of the local trees had gone with only sparse patches beside the agriculturally developed land (locally called *Cunucu*).

Already in 19th century descriptions (Teenstra, 1837), the Aruban countryside, in particular along the West coast, was characterized by its large open panoramas. The topological map of Werbata in early 20th century shows a predominantly agricultural land with fencings from locally available materials such as small rocks of diorite stone (locally called *tranchi*) or from the stems of columnar cacti (locally called *trankera*). Wireframe was used as well. Today, only few tranchi and trankera fences still exist and mostly only for their ornamental or cultural value in memorization of the former *Cunucu* landscape.

1924

Fuel oil

After World War I there was an increase in the demand for fuel, worldwide. With the discovery of new oil fields in nearby Venezuela, refining facilities were also built in Curacao and in Aruba. A spread of supply of oil refining products in the region was desirable for strategic and geopolitical reasons. The development of the oil refining industry undeniable launched the economy and welfare in Aruba. The establishment of the first *Oil refinery* was in 1924 in San Nicolas. It was run by the Canadian *Lago Petroleum Corporation* (Later: Lago Oil and Transport Company). At about the same time, in 1928, the *Arend* Oil refinery became operational by Dutch Shell and was situated at the Eagle Beach near Oranjestad. Both refineries processed crude oil from Venezuela and sold the refined products to the United States, respectively, the Netherlands. The industry boomed, in particular during WWI, and attracted many foreign workers as well as propelled local financial and facilitating business activities (Ridderstaat, 2007). The refinery had become Aruba's main economic pillar but fierce competition at the world market for fuel forced the Arend oil company to close its gates in 1953. At about the same time, the Lago Oil and Transport Company introduced new automated systems and technologies to lower for instance the costs in labor and personnel. At the end, in 1984, the Lago was equally forced to close its gates, causing an economic slowdown in Aruba. After years of uncertainty, the close downed refinery was sold in 1991 to Coastal Oil and reopened. In just over one decennium later, in 2004, the refinery was sold again. The new owner, Valero Oil Company, however, closed its gates in 2009.

The development of an oil refinery and transshipment station and the many storage tanks had brought devastating changes to the environment and coastal landscape that was until then still barely touched (besides by the gold and phosphate shipping activities). The impact from the oil refinery on the environment is poorly documented, partly because environmental awareness was not commonplace during the first half of 20th century. Contamination near the coast, however, had severe consequences for the marine environment (Bak, 1987). We will review some of the direct and indirect pollutive actions in and above ground. The information listed below is from a book on the oil refinery activities of the Lago Company (Ridderstaat, 2007) as well as from a study report to exploit natural water resources in Aruba (Finkel & Finkel, 1975).

A direct impact from the oil industry on the surrounding landscape is from leakage and dump sites above as well as below ground (Ridderstaat, 2007). During the transshipment activities in WWII, millions of barrels of oil leaked into the soil. Pits that had been originally dug for the exploitation of caliche[8] were used as easy dump sites for rubble and oily waste, heavy metals, sulphur and all other kinds of toxic waste. At a time during the war when fuel production was at its peak, pitches in the area along the southern coastline (Grapefield) were used to temporarily store tar residual. After the war, the tar was used for the production of briquettes but some open air tar pitches remained for years in the limestone landscape. Similarly, giant heaps of sulfur residual were stored in the open, near the coast, and were continuously taken by the wind and blown into the sea. The pollution of coastal waters lasted decennia.

The environment was affected in other ways as well. There was destruction of the coral reefs of the San Nicolaas Bay to gain better access for the large tankers to the oil terminals, and, there was a more intense exploitation of fresh water from local wells to meet the water requirements for the upcoming oil industry. Initial over-pumping had caused a drastic increase in salinity levels in many dug wells[9] (Finkel & Finkel, 1975). Closest to the coast, at the limestone rocks, the pumping of natural water from the wells was done with care, to prevent an up-welling of sea water. Already, it was practice to skim the water in between periods of rest, such that the well had time to recover, but the demand for freshwater was growing. To meet the requirements, a long skimming tunnel[10] was constructed. The tunnel still exists today.

In his book on the flora and fauna Freylinck described the countryside in the middle of last century as barren and almost without vegetation (Freylinck, 1950). At the time, much of the former agricultural land had already wildered and eroded. There had been periods of drought. Moreover, many farmers had gone to work in the oil refinery and had left their land abandoned. Goats were free to roam and graze the remaining vegetation. It is hard to say whether the salinization of the groundwater may also have had part in the change in the landscape. Causes and effects are hard to disentangle afterwards.

[7] Werbata (in Aruba represented by his student W. A. Jonckheer) had produced for the first time in history, an accurate topography of the landscape in Aruba over the period from 1909-1911 (Krogt, 2006)

[8] Caliche is an accumulation and deposition of minerals and carbonates that have leached from the upper into deeper soil layers.

[9] Wells in the island interior, at some distance from the coast, derived their water from aquifers in the crystalline rock and were less susceptible to salinization by over-pumping. The salinity freshwater levels of most of these wells' were however considered too high for long-term irrigation and agricultural use.

[10] www.lago-colony.com. Keyword: "Mangel Cora wells"

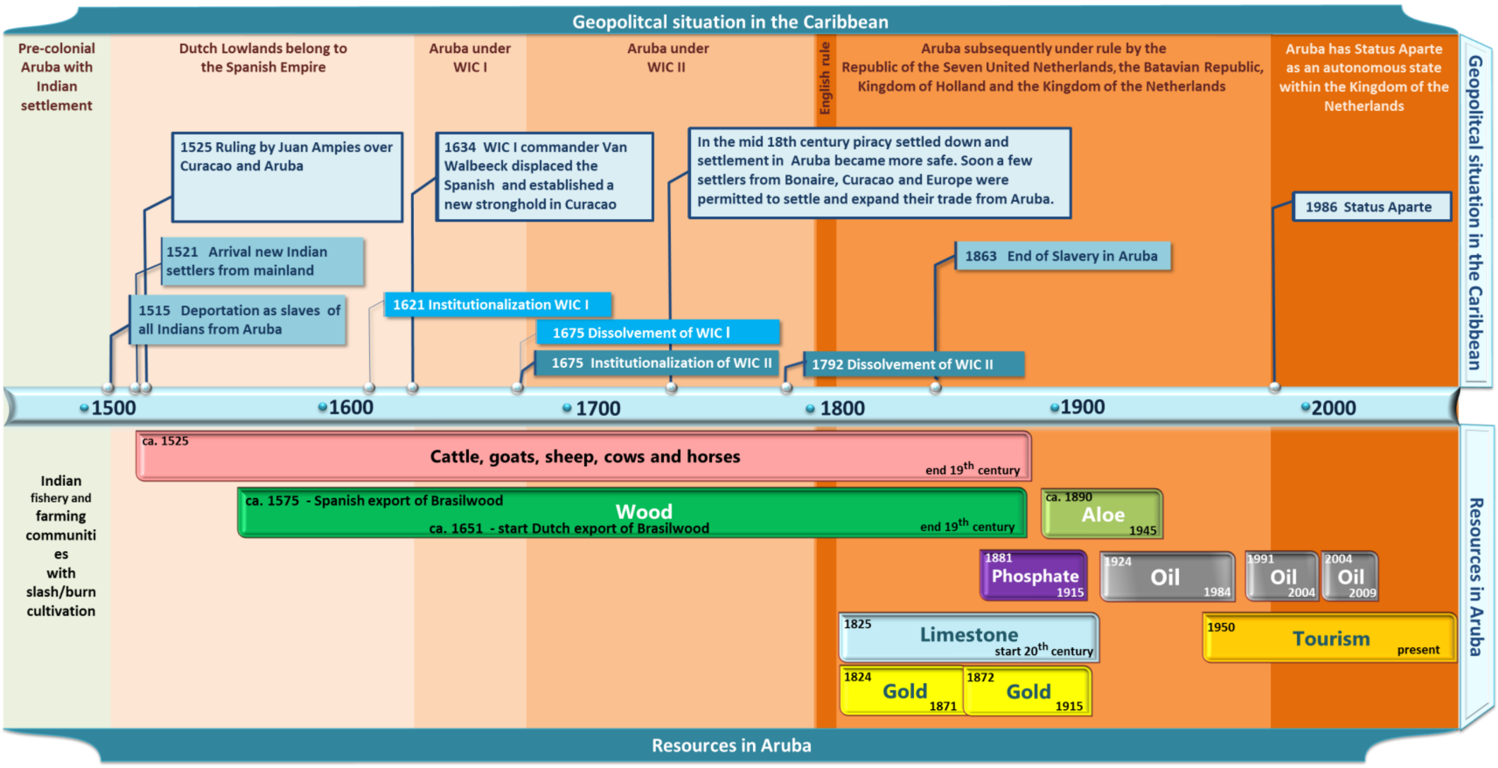
1960

Tourism

Not too long after WW II, in the early 1960s the *tourism* industry and alongside with it a strong financial sector offered the opportunity for a next impetus in the growth of the economy. The clear coastal waters, sandy beaches and the pristine natural scenery in the coastal region in the Northwest in particular, shaped a sound basis for continued attraction by tourists. Even so, the development of the tourism industry also brought major changes in the same the landscape.

In particular in the region Noord, housing and land development increased drastically. The hotels at the coast did not only provide work but also propelled the establishment of commercial and recreational centers. Like the refinery had played an important economic role in leveraging the labor market, the tourism and facilitation industry similarly proved to be a strong economic pillar for the years to come. Today, the island economy depends almost exclusively on visiting tourists, which in turn, puts high responsibility to maintain a healthy coastal ecosystem.

Figure 1 Time line representation to show the history of natural resource utilization in Aruba in perspective with relevant geopolitical events



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Landscape series: 3

A review of Geology, Climate and Hydrology in Aruba

Photo by: Stan Norcom - Limestone Terraces along the Northeast shoreline
From: www.lago-colony.com

The Aruban landscape has undergone many changes in history. This paper is part of the landscape series:
"Spatial Developments in the Aruban Landscape: A multidisciplinary GIS-based approach derived from geologic, historic, economic and housing information"

2016

Contents

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Aruba
2016

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This paper is part of a series on the developments that relate to the Aruban landscape. To bring perspective to current environmental threats and developments we review in this paper the geological and (paleo)-climate history of Aruba. Good knowledge of present but also of past processes is vital to understanding the effects that urbanization and economic progress pose on land and marine ecosystems.

Geological history of Aruban landforms

The tectonic history of the Caribbean is not yet fully understood. Different models attempt to explain the different processes involved, in particular with respect to the position and origin of the Caribbean plate. The most popular theory explains the formation of the Caribbean Plateau by the entrapment and relative movement (in east-west direction relative to a fixed North American continent) in between the separating and westward migrating North- and South American Plates[1]. Ahead of the Plateau developed the Caribbean Great Arc by a series of volcanic eruptions, relatively pushed eastwards in between the separating North and South American continents, forming todays' Islands on the edge of the Caribbean Basin. An overview of this so-called *Pacific-origin model* is given by Pindell (2011) and Boschman (2014), and outlined below in order to gain better understanding of the history of Aruban geological features. Following an alternative, so-called *in-situ model*, originally proposed by James (2005), the Caribbean Great Arc never existed and the origin of the Caribbean Basin and the Islands in the region developed in-situ, i.e. they origin from a Proto-Caribbean Ocean crust at about the place where these situate now and not in the distant Pacific. However, evidence from Pacific type fauna in the Caribbean and from the complex distribution and pattern in geochemistry of old rocks against the South American continent favor the Pacific-origin model (references can be found in Lely et al., 2010). We describe the more popular models below.

~ 93Ma

'Great (Caribbean Islands) Arc'

In the Late Cretaceous, some 100-93 Ma (Mio yrs. ago; see endnote), a volcanic islands arc system formed, the '*Great Caribbean Islands Arc*' *(the later Caribbean Islands)*, *east of a subduction* zone where the Pacific Ocean crust (Farallon Plate) submerged under the Proto-Caribbean Ocean crust. As the North and South American Plates were separating and moving northwestwards this gap in between, the Proto-Caribbean Ocean crust, was so to say in collision with the Pacific Ocean crust. The volcanic basement of Bonaire (*Bonaire Washikemba Formation-BWF*) cropped out at the southern end of the Great Arc. Accordingly, the basement of Bonaire has in its earliest origin a different tectonic evolution then the Aruba - Curacao basement (Lelij, et al., 2010) that is argued to have its origin *more to the West* as part of a basaltic intrusion pushing upwards inside the Farallon Plate.

[1] The movement of the Earth's continents relative to each other is called continental drift; after Wegener, 1912. The Caribbean Plate was engulfed by westward migrating North and South Americas.

~ 91Ma

Basaltic Oceanic Plateau

A large basaltic flooding on the Farallon Plate, the *Caribbean Large Igneous Province (CLIP),* occurred below sea level, at approximately 91-88 Ma ago, at a location off the coast of present-day Colombia in todays' Pacific (White, Tarney, Klaver, & Ruiz, 1996). The Aruba-Curacao lava basement is a detached remnant part of this intrusion and the origin of both the *Aruba Lava Formation (ALF*) as well as the *Curacao Lava Formation (CLF*). In its relative movement eastwards it collided against the Proto-Caribbean Ocean crust and against the *Great Caribbean Islands Arc*.

~ 88Ma

Magmatic intrusions

As the Farallon Plate moved farther in between the North and South American Plates, there was a reversal of the subduction zone. The Proto-Caribbean Ocean crust went on now descending under the Farallon Plate and causing new magmatic activity, but now to the west of the subduction zone. Consequently, about 3 Mio years (~88 Ma) after the proto-Aruba Lava Formation had stopped intruding the Farallon plate and had been cooling, a new magmatic intrusion occurred on one section of the Oceanic Plateau, named the *Aruba Batholith* (see page 5). The Batholith is typical for Aruba and is not present in Curacao (or in Bonaire) (Lelij, et al., 2010).

The forces of the collision and magmatic intrusions caused metamorphic rock formations in the older *Aruba Lava Formation rocks* (see page 4). In time, the Aruba-Curacao basement moved on the edge of the new *Caribbean Plate* towards the southern margins and underwent a complex series of deformations against the South American continent. The Great Caribbean Island Arc moved further on the edge of the deformation zone north and southeast. The part that was to become the *Greater Antilles* moved all the way towards its current position, at the northeast border of the Caribbean Plate.

~ 75Ma

Collision with South American Plate

At about 75-73 Ma at the margins of the forming Caribbean Plate, accretion, convergence and thickening of the oceanic crust took place. As the north-eastwards migrating Caribbean Plate *collided with the South American Plate*, the submarine basement of Aruba and Bonaire (defined as discrete areas within a single Block) was deposited successively against the South American Plate (first Aruba at about 70-60 Ma ago and later Bonaire at ~50 Ma ago). The basements of Bonaire and Aruba/ Curacao had a different origin, but were positioned next to each other. Their distinct history from the collision, strike slip displacements and accretion against the South American Plate and renewed heating of the rocks (Lelij, et al., 2010) shaped a somewhat different landscape.

~ 70Ma

Uplifting

At the margin of the Caribbean Plate, Aruba was positioned in a very complex zone with tectonic interactions. The relative motion of the Caribbean Plate against the South American Plate caused a deformation zone with several plate fragments and blocks to strike and slip against the South American Plate. The *Aruba-Curacao-Bonaire Block* is such a block and estimated to be about

1,000 km long and 300 km wide. Along the thrust, strike and slip faults, moments of subsistence and land uplift occurred. Figure 1 gives an impression of the many faults that are still recognizable at the surface. The uplifting of the leeward Antilles occurred 70-60 Ma ago, about 500 km westwards from Aruba's current relative location. During the uplifting, parts of the original Basalt formation, came to the surface in all three islands. Evidence from paleo magnetic studies suggest that over subsequent displacements, the islands rotated clockwise at least 90° relative to a more stable South America continent (references in Boschman et al. (2014)).

Evidence is found today in the strike and slip fault patterns that run more or less parallel to the diffuse boundary between the two plates and evidence is also found in the direction of Quartz and calcite veins within the rocks (Beardsley & Avé Lallemant, 2005). Today, in Aruba, the strike and slip fault activity can still be felt from shocks and temblors on a quite regular basis[2].

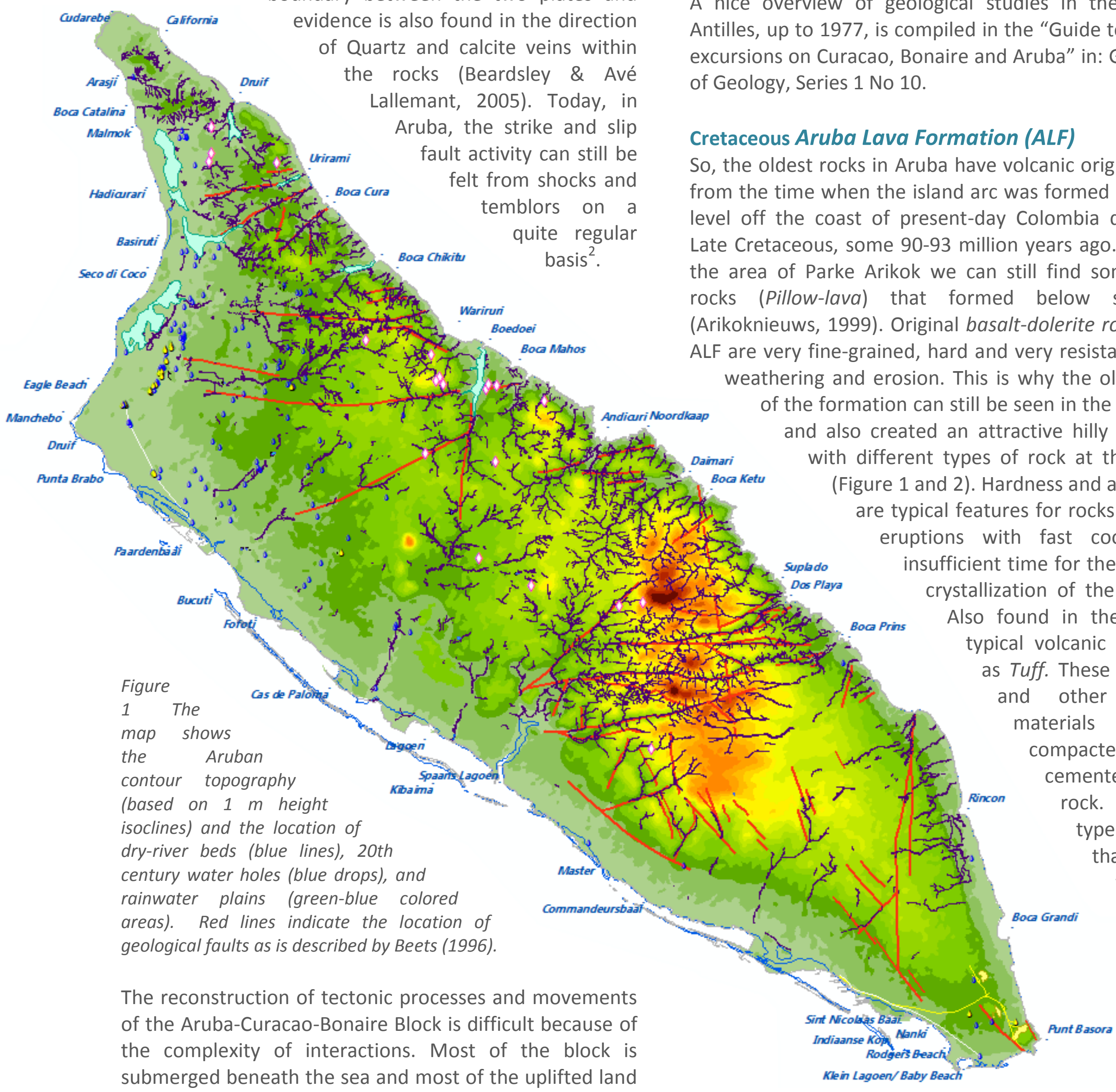

Figure 1 The map shows the Aruban contour topography (based on 1 m height isoclines) and the location of dry-river beds (blue lines), 20th century water holes (blue drops), and rainwater plains (green-blue colored areas). Red lines indicate the location of geological faults as is described by Beets (1996).

The reconstruction of tectonic processes and movements of the Aruba-Curacao-Bonaire Block is difficult because of the complexity of interactions. Most of the block is submerged beneath the sea and most of the uplifted land is under thick layers of sediments. Also there is still continental growth of South America as the South American Plate interacts with the Caribbean Plate (Curet, 1992).

Geomorphology of different rocks

Most of the Aruban basement consists of solidified molten rock from magma that has its origin deep below the surface of the earth crust during different episodes. These rocks are generally called *igneous rocks* with *volcanic* origin (when the magma erupted and quickly cooled as was the case with the Aruba Lava Formation) or *plutonic* origin (when later magmatic bursts remained within the earth's crust and cooled slowly, such as with the Aruban Batholith). Plutonic rocks are more coarse-grained than volcanic rocks and have larger crystals because with the slow cooling, the minerals had more time to move and crystalize. Grain size and chemical composition of the rocks is an important determinant for the resistance against later erosion.
A nice overview of geological studies in the Leeward Antilles, up to 1977, is compiled in the "Guide to the field excursions on Curacao, Bonaire and Aruba" in: GUA paper of Geology, Series 1 No 10.

Cretaceous *Aruba Lava Formation (ALF)*

~ 91Ma

So, the oldest rocks in Aruba have volcanic origin and are from the time when the island arc was formed below sea level off the coast of present-day Colombia during the Late Cretaceous, some 90-93 million years ago. Today, in the area of Parke Arikok we can still find some of the rocks (*Pillow-lava*) that formed below sea level (Arikoknieuws, 1999). Original *basalt-dolerite rocks* in the ALF are very fine-grained, hard and very resistant against weathering and erosion. This is why the old remains of the formation can still be seen in the landscape and also created an attractive hilly landscape with different types of rock at the surface (Figure 1 and 2). Hardness and a fine grain are typical features for rocks from lava eruptions with fast cooling and insufficient time for the complete crystallization of the minerals. Also found in the ALF are typical volcanic rock such as *Tuff.* These are ashes and other erupted materials that are compacted and cemented into a rock. Another type of rock that can be found are *Conglomerates* that are formed from loose particles and other clast sediments cemented together by the heat of pressure underneath the earth crust.

[2] http://es.earthquaketrack.com/p/aruba/recent

Most of these rocks however are transformed under the influence of pressure and heat[3] and become *metamorphic*[4] like *schist rocks.*

~ 88Ma

Cretaceous *Aruba Batholith*

The magma that cracked from under the partially solidified lava and intruded the older volcanic rocks is called the Aruba Batholith. Studies show that the batholith intrusion occurred in a sequence of several bursts not too long after the Aruba Lava Fm. stopped erupting (in less than 3 Ma) (Lelij, et al., 2010). Earlier magma had not been cooled completely yet (White, Tarney, Klaver, & Ruiz, 1996).

The big magmatic body, the Batholith, composes predominantly of *tonalite and quartz-diorite* rocks[5]. Earlier smaller intrusions with *Gabbro* (near Bushiribana and Matividiri) and later with *Hooibergite* (hornblende-rich diorite) are also part of the Aruba Batholith. Most of these rocks have about the same origin but differ in chemical composition and silicate (quartz) content.

The *Hooibergite* intrusion was one of the later thermal pulses during the development of the Batholith.

Thus, the Hooiberg is not an old volcano even if it looks like one, but the remains of a magmatic intrusion of the Aruba Lava Formation that contained relatively hard rock material and survived deformation, uplifting, erosion and weathering (van den Oever, 2000).

The large Diorite boulders in the Aruban landscape only exist in Aruba and clearly show the processes of physical and chemical weathering that we will discuss later.

Dykes and Veins

The contraction or expansion in rocks upon solidification, folding of land masses, earthquake shocks and line displacements cause fissures. Such fractures and cracks were later filled with magmatic intrusions and with sediments and minerals that solved in water and seeped into the cracks. Large longitudinal fissures are sometimes recognizable as narrow often straight-walled dykes that still exist because their harder material survived erosion better that than the original rock did.

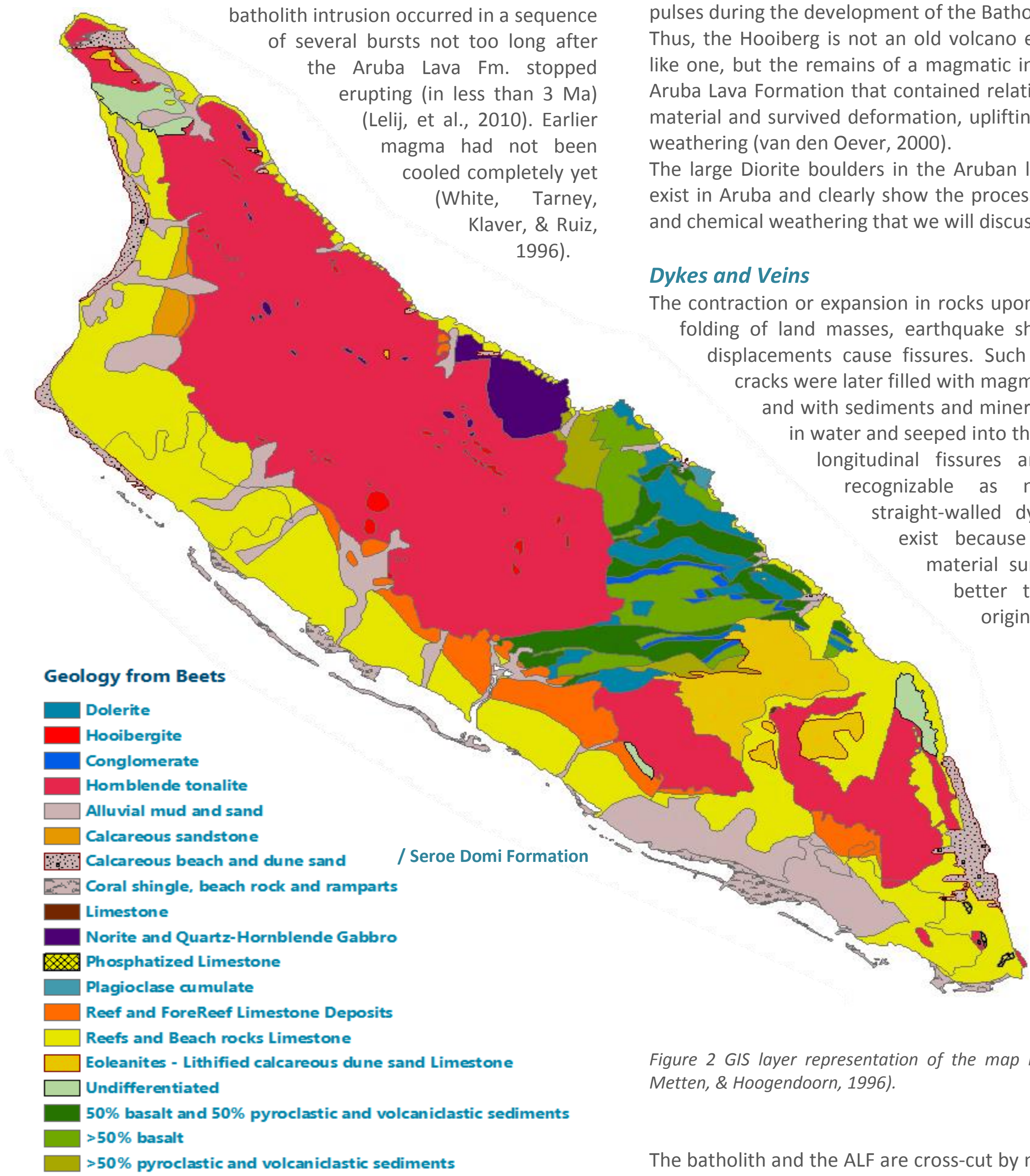

Figure 2 GIS layer representation of the map by Beets (Beets, Metten, & Hoogendoorn, 1996).

The batholith and the ALF are cross-cut by numerous such *dykes* but also by *veins*. Veins are similar in origin but distinct because they have irregular, shorter and discontinuous shapes. The diorite embedded quartz veins in Aruba are known as they sometimes contain gold ores (van den Oever, 2000).

[3] A nice introduction to Petrology, the study of the origin, occurrence, structure and history of rocks, is found online: http://www.brocku.ca/earthsciences/people/gfinn/petrology/defn.htm

[4] Rock metamorphism occurs when the original rock has been subjected to high pressures and temperatures and has been transformed into another form.

[5] The difference is based on quartz or SiO_2 (Silica) content: **quartz-diorite** contains >5% quartz and **tonalite** contains >20% quartz.

~35- 24Ma

Paleogene (Eocene) Lime stone deposits

From the time of Late Cretaceous to Middle Miocene only an incomplete record of coral fore-reef debris and sediments from the South American mainland remained. The oldest remains of the erosion sedimentation are from Early Oligocene/Eocene (approx. 35 Ma), observable on the surface in Butucu. Slabs from a borehole in Oranjestad (Helmers & Beets, 1977) reveal Eocene Limestone sediments from Early Miocene (approx. 24 Ma).

~ 15- 0.5Ma

Neogene Seroe Domi Formation

More articulate are the uplifted layered thick carbonate sediment depositions with underneath different limestone deposits that date from Early/Middle Miocene until probably the Middle to Late Pleistocene (approx. 15 Ma-0.5 Ma). This is the so-called *Seroe Domi Formation* that typically consists of large flat multi-layers of limestone coral debris with eroded earlier Reef and Fore Reef from a Miocene high sea level stand. The Seroe Domi Fm. exists in Aruba, Bonaire as well as in Curacao where it is more visible in the landscape.

In Aruba, the areas northeast of Pos Chiquito, Savaneta and San Nicolas and an area east of Bubali Plas and at Seroe Cristal near the Northeast coastline (Figure 2) show the remains of *Seroe Domi Formation*. Like in Curacao, the stratification of these layers appears at some places clearly tilted. Today, it is the generally accepted view that the long-term processes of deformation and land uplift of the Aruba-Curacao-Bonaire block against the South American continental margin has been accompanied by a folding and tilting of the Seroe Domi Formation complex. There is, however, still some debate about whether these undulating limestone layers reflect the folding of a top earth crust (compression during early Pleistocene) or simply is the consequence of sedimentation along a dip in the original sea bedding. In his PhD Thesis (1979), Herweijer studied the Seroe Domi Formation and the likely occurrence of compression after deposition of the thick carbonate sediment layers on top of the heavily eroded Cretaceous basement (the remains of the ALF/Batholith complex).

~1.1- 0.1Ma

Quaternary Pleistocene Eolianite sanddunes

In the National Parke Arikok and the area of Jaburibari we find fossilized cliffs of Pleistocene eolianite[6] rocks, i.e. solidified grains of former wind-blown sand dunes. These lime-sands hardened and fossilized into the *eolianite limestone rocks*. They are a reminder of the rich shallow-marine life and coralgal communities with carbonate content that after depositing and surfacing have been blown by the winds into undulating sand dunes (Herweijer, 1979).

~ 0.6- 0.1Ma

Quaternary Late Pleistocene Limestone Terraces

The Pleistocene is commonly known for the alternating periods of advance and retreat of the Arctic and Antarctic ice cap. As a consequence of the advance and retreat of the ice sheets the sea levels slowly changed worldwide. The climate change came with *dryer and colder climate during Glacial* and *warmer and more humid climate conditions during Interglacial*. At the more regional level however, climatic conditions may have varied more abruptly followed by prolonged periods of change in regional temperature, precipitation and humidity.

A difference of approx. 120 m exists between the lowest seawater highstand only some 18,000 yrs. ago at the end of last Pleistocene glacial period and the highstand in current Holocene Interglacial (Lambeck, Yokoyama, & Purcell, 2002). Today, global sea levels are still rising, but less strong as in early Pleistocene and with only a few meters since the middle Holocene (over the last 5,000 yrs.) (Hodell, et al., 1991). The cause of this sea level rise is not to be confused with the very recent sea level rise caused by global warming and the buildup of greenhouse gasses in the atmosphere.

The subsequent sea level cycles in the Caribbean during Pleistocene (following the Glacial and Interglacial periods) with a continuous uplift of the land, have created a staircase of coral reefs banks by the interplay of land uplift and reef growth and erosion. The terraces surrounding the Aruba Batholith and the Aruba Lava Formation are the fossilized deposits and remains from these processes, cemented together into sedimentary limestone rock. Each of the raised shorelines is found to correspond to a specific period of highstand of the sea level (Eisenhauer & Blanchon, 2001).
In Aruba, only a few terraces have remained at different heights above sea level. Initial studies by Westermann (1932) and De Busonjé (1974) broadly discern a 'Higher', 'Middle' and 'Lower' Terrace surrounding the Aruba Batholith\ ALF complex. These limestone terraces are the remaining evidence of coral reef deposits during the final phases of different Pleistocene high sea level stands. The continuous uplifting of the ALF/Batholith has brought these Terraces above current sea level. The oldest terrace is situated on the highest grounds, but terrace building is a process that is still active today.

Based on a more complete record of Terraces in Barbados (Muhs, 2001), we know that in Aruba some terraces have not survived and must have been eroded completely. The thick Seroe Domi Fm. eroded and washed away for a large part. Along the southwest coast, where waters had been calmer, the Limestone deposits and erosion fields (and the remaining parts of the eroded Seroe Domi Fm.) however still cover most of the areas today. It is on the lowest and youngest of these terraces that most of the Aruban Aloe cultivation took place in early 20th century (see Figure 5).

Paleoclimate records

Little information is available about the more recent paleoclimate events that shaped the Aruban landscape.

[6] Eolianite refers not to a specific time period but to the type of process that formed the rock, that is, Eolianite rocks found their origin in compaction of sediments that have been accumulated by wind into for instance coastal dunes (formed into coastal limestone or sand dunes).

Sediment core records show that in the past the landscape must have been quite different.

A pollen record from a bore hole in Oranjestad (Helmers & Beets, 1977) shows spores of ferns and palms (A. Curet, pers. comm., 2015), possibly from early Miocene origin (23-15 Ma). Proxy[7] studies, like palynological research (pollen and spore research), oxygen isotope[8] and more recently x-ray fluorescence measurements of sediment components have shed some light on the paleoclimate history in the Caribbean. We describe some major findings, next.

Wet and dry periods

In a detailed study of sediment cores in Lake Miragoane, Haiti, published in Nature (Hodell, et al., 1991), changes in the lake water levels have been reconstructed on the basis of oxygen isotope[9] analyses. Information about past wet and dry conditions was compared with a corresponding analysis of vegetation communities, based on pollen zonation research. The overall pattern in the Haitian Lake samples shows that after the end of the last Glacial[10], from *early Holocene* at about 10,500 BP[11] up to about 5,400 BP, precipitation levels and climate temperatures had increased. Hence, the circumstances in the Caribbean have been (over thousands of years) much wetter than today. From about 5,400 BP onwards, from the mid to late Holocene up to today, climate turned to dry conditions.

~ 5400 BP

Nearer to Aruba, in Bonaire, another study, by Giri (2013), shows similarly that *during mid-Holocene local climate was dominated by high and intense levels of precipitation, particularly during the summer*. These findings were based on oxygen isotope analysis from (marine) coral samples, off the coast in Bonaire.

Major deviations in the annual isotope ratios revealed fluctuations in marine salinity between summer and winter seasons. The process behind these fluctuations was argued to be intense rainfall during the summer seasons.

Today, in contrast to the situation in Mid-Holocene, marine hydrological conditions in the Southern Caribbean Sea are best characterized by the elevated evaporation in winter and the strong (wind-driven) oceanic surface currents that carry large freshwater concentrations from far away, from the seasonal discharge of the Orinoco and the Amazon rivers.

The dynamic relationship between the marine hydrology and the regional climate and the dominating effect thereof on local circumstances reflect a southwards shift of the so-called Inter Tropical Convergence Zone[12] (ITCZ) *throughout the Holocene*.

Aside from these general trends that we mentioned above, Hodell (1991) described in-between climate alterations that may have maintained over many years and that seem to have been stronger than might be expected on the basis of the annual shifts in the *received solar radiation*[13] alone. The study suggests that while long-term fluctuations in received solar energy dictate climate and sea level changes (Glacial and Interglacial Periods) and consequently propel regional changes towards dry or wetter conditions, additional forces such as a drastic shift in the salinity of sea currents may have created temporal alterations in local climate (Metcalfe, Barron, & Davies, 2015).

One such abrupt variation in climate conditions (thus a large climatic change in a relatively short time span) occurred at about 8,200 yrs. BP, when conditions suddenly turned more humid due to an increase in precipitation (Hodell, Curtis, & Brenner, 1995). A rather abrupt onset of dry conditions occurred in Haiti at about 3,200 BP and again at about 2,400 BP. Based on the findings from the lake in Haiti, the ratio of precipitation/evaporation only switched back to the levels from before 2,400 BP at about 1,500 BP (500 AD), indicating the end of period of *temporary* drought that lasted 900 years (Hodell, et al., 1991).

~ 8200 BP

~ 3200 BP

~ 2400 BP

Beside information about local climate variations, there is evidence that suggests a coincidence of climatic fluctuations across the Caribbean. Recent studies, for instance, confirmed that the fall of the Mayan Culture in Mexico was indeed consequential to repeated periods of a Caribbean-wide drought between about 1,240 BP (760 AD) and 1,090 BP (910 AD) (Peterson & Haug, 2005). During this time span there have been at least three

~ 1240 BP

[7] Climate proxy studies are based on preserved physical characteristics of the past that enable scientists today to reconstruct the past climatic conditions. Definition: wikipedia.org

[8] Oxygen Isotope analyses is based on the difference in weight between the light oxygen atom ^{16}O (8 protons and 8 neutrons) and the heavy oxygen ^{18}O (more neutrons). Since water molecules with oxygen^{16} are lighter these molecules will evaporate more readily. The ratio between the two thus tells something about the conditions of evaporation or precipitation in the environment at the time of allocation in the sediments.

[9] Due to a difference in mass, differences in relative Oxygen isotope concentrations (O^{18}/O^{16}) express differences in evaporation relative to precipitation (H_2O^{18} is a fraction heavier and precipitates easier that the lighter H_2O^{16}).

[10] Ice ages (Glacials) typically occur in intervals of about 40-100 Ma. In between there are shorter interglacial periods such as the current one (Holocene) that are characterized by a retreat of the ice sheets and a warmer favorable climate. As the ice sheets retreat, sea levels rise first rapidly but then gradually up to the level of today. There is little change (3-5m) over the last 7,000 yrs. (Lambeck, Yokoyama, & Purcell, 2002) The general believe is however that human action contributes significantly to recent global warming and sea level rise

[11] BP indicates the timescale Before Present (dd. 1950) and is not to be confused with BC (Before Christ). 8,200 BP equals approx. 6,200 BC.

[12] The ITCZ is the area encircling the earth near the equator where the northeast and southeast trade winds come together. The location of the ITCZ varies over time influenced by the sun's position and the differentially warming hemisphere (Schneider, Bischoff, & Haug, 2014) (Haug, Hughen, Sigman, & Röhl, 2001).

[13] There is an annual shift in the *received solar radiation* that reflects the slow shift of the annual orbit of the earth around the sun. This movement dictates long-term but slowly varying levels in received solar radiation and these are largely responsible for the Glacial and Interglacial periods.

multiple-year periods of drought in the Yucatan Peninsula with an accumulation of the known social implications that led to the end of the Mayan Culture. The authors supported their conclusions on the basis of x-ray fluorescence measurements of trace elements and foraminifera data from cores in the Cariaco Basin, off the coast of Venezuela (at quite some distance from the Yucatan). Their data coincided with the earlier findings by Hodell in a lake in the Yucatan Peninsula, Mexico (Hodell, Curtis, & Brenner, 1995), and provided very detailed information about the shifts in precipitation and in marine salinity levels.

~ 1200 BP

The change towards generally dry conditions in the Caribbean in Late Holocene (approx. ~1,200 BP) is also supported by a study by Gregory et al. (2015) in two coastal lagoons in Cuba. Differential presence of specific foraminiferal assemblages reveals a shift in relative lagoon water salinity while a shift in the composition of trace elements in sediment core samples reveals a change in rainwater runoff into the lagoons corresponding to less precipitation.

A nice overview of the spatiotemporal pattern of climatic fluctuations across Central America and the Caribbean during the Holocene (including an overview of underlying studies), is given by Metcalfe (2015). The spatial, multi-annual, and even seasonal mapping of the climate in the Caribbean is complex, however. Their summary of studies suggests that wetter and drier conditions occur alternatively under the influence of factors, other than the decline in seasonal insulation and the displacement of the ITCZ alone. The authors reason, that the successive pulses of glacial ice water entering the region may have an impact on the climate as well. The occurrence of intense hurricane seasons, for instance, may also challenge a proper understanding of the paleoclimate conditions as these may mask periods with relative drought (Frappier et al., 2014; referenced in Metcalfe et al., 2015).

Unfortunately, paleoclimate information from Aruba is scarce. It would be interesting to reconstruct more precisely the climatic conditions that have dictated the vegetation growth and fauna abundance in Aruba for instance during recent Holocene and be able to understand the current landscape more precisely.

A pilot study in Aruba (Nooren, 2008), based on pollen analyses from sediment cores at the *Boca Prins bay inlet* (Northeast coast) and at a site in the *Spanish Lagoon* (Southwest coast), suggests a change in vegetation type and cover in line with described climatic fluctuations. The characterization of the sediment cores from the pilot study even suggests evidence that relates to the dramatic impact by man on the landscape from deforestation, grazing and heavy erosion in recent colonial times, as has been described in literature already (Hartog, 1953). In the youngest of sediment records from the Spanish Lagoon site, for instance, clastic material (seen as evidence for erosion) was observed together with charcoal[14] remains, whereas such type of sediment layer was absent from the periods before. The presence of charcoal and clastic sediments coincided with a peak in the occurrence of *Pal'i sia Cora* pollen (Bursera *simaruba*) in these layers. The high occurrence of '*Pal'i sia Cora'* pollen is indicative that there was a dry tropical forest in the surroundings of the lagoon up to that time. The timeframe clearly corresponds to the period of early *colonization* when deforestation occurred from the intense wood harvesting and the free-roaming of herbivore grazers. Consequential increased erosion seems in line with these events.
Such (preliminary) data also show that the inland bay in Spanish Lagoon was much larger in the past than it is today. Mangrove forests (Rhizophora *mangle*) were present already since approximately 7,000 BP. Pollen analyses of the old mangrove peat indicate relatively wet conditions (pers. comm. Nooren, 2015) with the presence of many fern spores, which were absent in the younger deposits.
Today, both bays are filled with sediments. The bay at Boca Prins is almost completely filled with erosion material from the hills in the hinterland. In the *Boca Prins bay inlet* there is only one thin organic layer found, at 3.3 m depth, that reveals a temporary presence of Mangrove forests (Rhizophora *mangle*), whereas the remainder of the sediment core is almost exclusively from mineralogical content. Slabs suggest that the Mangrove vegetation was displaced by a more terrestrial tree species, Buttonwood (Conocarpus *erectus*). Interesting is the fact that the core records from before the loss of Mangroves do also show spores of fern that were absent in all the younger records.
Such abrupt destruction of mangrove assemblages and the alteration of pollen spectra reveal a subsequent domination of more dry and open hinterland pollen types. Findings by Engel et al. (2009) in Bonaire suggest the occurrence of extreme wave events at about the same time. Whether there is any concurrence of events may be interesting to investigate in more detail. Such studies, however, suggest intense paleoclimate events that may have had a lasting impact on vegetation and landscape.

Data collected relatively near to Aruba, in the Cariaco Basin off the coast of Venezuela, show that dry conditions with precipitation minima occurred from 3,800 to 2,800 BP (Haug et al., 2001). The climate and vegetation cover then may accordingly have been different from today[15]. *~ 3800 BP*
Artifacts and large shell midden show that pre-ceramic people may already have visited Aruba incidentally in Mid-Holocene, i.e. since ~4,000 BP[16] (Versteeg & Ruiz, 1995). Preceramic Indian inhabitants in Aruba had a hunting/fishing and gathering lifestyle and mainly occupied the coastal areas, including the Spanish Lagoon.

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[14] Micro-charcoal remains in sediments associate clearly with fires. The distinction between natural and anthropogenic fire regimes is however difficult to establish and are cause for debate.

[15] Based on received solar radiation today we typically live in a *relatively dry time zone*

[16] The **Preceramic period** in Aruba is estimated to start at about 4,000 BP and last until 1,000 BP. The **Ceramic period** is described to last from 1,000 BP to about 500 BP when Spanish colonization began.

The oldest dated shell deposits associated with human occupation on the island were found in Rooi Bringamosa near the Spanish Lagoon. A charcoal sample from this shell layer in the pilot study of Nooren revealed an AMS[17] 14C date of 3,260 +/-35 BP (calibrated age of 3,500 +/-50 yr. BP at 68.2% probability) (pers. comm. Nooren, 2015, unpublished data). Nooren also confirms that fossil pollen and spores from that time span identify plant species that are now hardly found (pers. comm., 2015).

~ 3500 BP

Interesting is the fact that Ceramic (Dabajuran) Indians arrived at about 1,200 BP (800 AD) in Northern Venezuela and at about 1,100 BP (900 AD) in Aruba (NAM, 1999). It is possible that climate change-induced migration (Gupta, Anderson, Pandey, & Sanghvi, 2006) (Laczko & Aghazarm, 2009) played a role here as well, and, that the onset of dryer climate conditions, such as occurred at about 3,800 BP and again at about 1,200 BP, was coincidental to the timing of settlement of the new arrivers.

Current Climate Conditions

Regular monitoring of climatic conditions occurs since the early 20th century (Meteorological-Yearbook, 1933-1972). We present in figure 3 and figure 4 climate measurements from 2000-2011 at Reina Beatrix Airport in Aruba (Year reports Statistics of the Meteorological Observations in The Netherlands Antilles: 1955 - 1972). Earlier data can be found at www.meteo.aw.

Figure 3 a-d (top) show climatological records collected at Reina Beatrix Airport during the period 2000-2011. The four graphs show the average monthly records for temperature, total precipitation, number of rain days and relative humidity.
Note: A rain day is a day with at least 1 mm rain.
Source: Statistical Yearbooks 2000-2011. CBS, Aruba
Figure 4 a-d (below) show climatological records collected at Reina Beatrix Airport during the period 2000-2011. The four graphs show the average annual records for temperature, total precipitation, number of rain days and relative humidity.

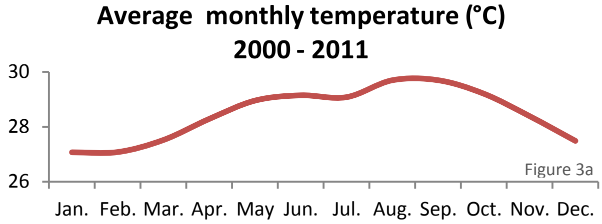


Figure 3a

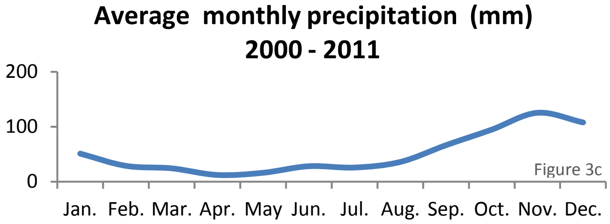


Figure 3c

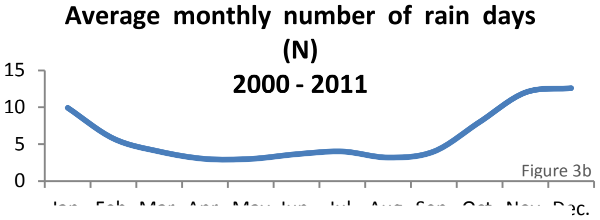


Figure 3b

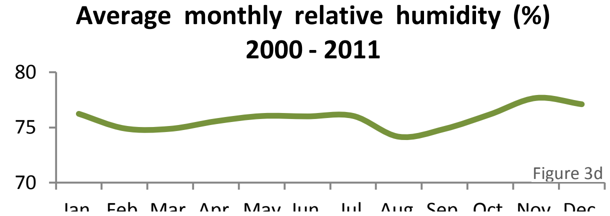


Figure 3d

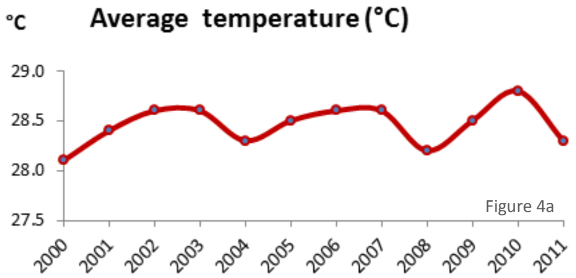


Figure 4a

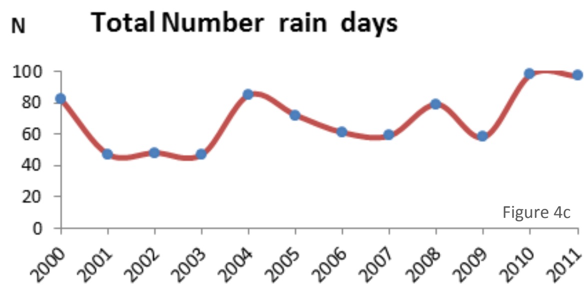


Figure 4c

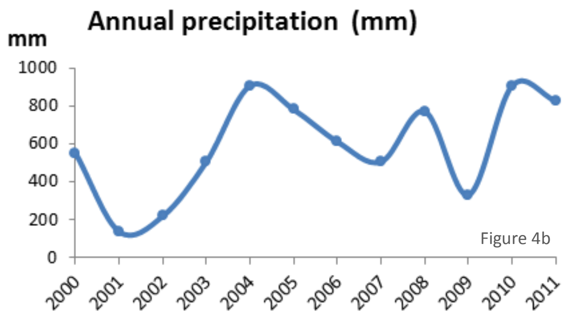


Figure 4b

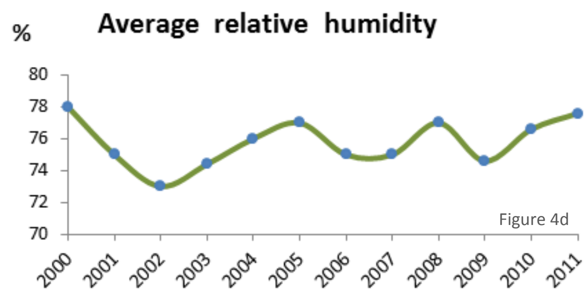


Figure 4d

[17] Accelerator mass spectrometry (AMS) is a type of carbon dating technique.

Temperature

In Aruba, we observe little variation in daily temperature (Figure 3a). Values fluctuate between an average low of about 27 °C during the coldest months, January and February, up to 30°C during the hot summer months, August and September. Year averages remain quite uniform as well in the range of 28°C and 29°C (Figure 4a).

Precipitation

In contrast to the slight fluctuation in temperature the fluctuation in annual precipitation is more extreme (Figure 4b). Over the 10 year period, extremes occur in 2001 (137mm) and in 2004 (906mm). Considerable fluctuation exists between consecutive years. The latest decennium appears to have been quite wet at Queen Beatrix Airport, as we have to go back to the mid-50s to observe similar levels of rainfall. Rainfall in 1955 and 1956 (respectively 816 and 679mm average annual rainfall) is comparably high to the level of rainfall in 2004 (906 mm), 2010 and 2011 (respectively 906 and 826mm). The average annual rainfall over the period 2000-2011 is 587.9 mm and that is well above the long-term average of 410 mm over the long period 1953-1972.

Number of rain days

Precipitation is strongly influenced by the presence of tropical storms and/or hurricanes in the region. Therefore, it is important to realize that successive years with heavy rainfall as in the recent decade can be deceiving and do not necessarily represent a change in local climate conditions.

Rainfall generally peaks in November-December (rainy season), but in the rest of the year significant number of rainy days exist as well (Figure 3b and 3c).

For instance, August 2011 had 211.6 mm of rain but this is exceptional. The month of April is generally with the least rain, though it is not necessarily the driest month.

Interesting to note is that in contrast to the north-western Caribbean there are no distinct two rainy seasons. The precipitation pattern in Aruba is a unimodal late annual rainy season as described for south-eastern Caribbean islands.

> *August and September are considered the hot and dry summer months (March is considered dry as well) and November and December are the coolest and wettest months.*

Finkel and Finkel (1975) analyzed total rainfall per location and estimated rainwater drainage area. They suggested a descending gradient in rainfall from Southeast to Northwest in Aruba, in concurrence with the orientation of the Northeast Passat winds and the descending gradient in height topography of the island.

Humidity

Average annual humidity ranges between approx. 73% and 78% (compare Figure 4b, 4c and 4d) and roughly co-varies with annual number of rain days (ranges between 47 and 97 days) and annual precipitation (ranges between approx. 350 mm and 950 mm).

Over the period 2000 to 2011 the average monthly humidity was highest in the month November (77.7%) and lowest in August (74.2%), but the difference remains small (Figure 3d).

Sea surface temperature is an important determinant for precipitation (Karmalkar, 2013). Measurements of sea surface temperatures in the Southern Caribbean show that the highest annual sea surface temperature in the Southern Caribbean is in September[18] (no CBS data available), which is consistent with the timing of the onset of the wet season.

The descriptions of rainfall above provide no information about the intensity of rainfall. Commonly, rains pour down in heavy short showers. Under such conditions the runoff is strong and the effect of erosion on top soils severe. In particular when logging and land clearance has just taken place, heavy rains amass into large brownish runoff streams that carry topsoil and sediments towards the sea.

Hydrogeological structure

Next, we will review and describe some *hydro-morphological processes* in Aruba to better understand the effects of erosion, weathering and soil formation.

Earlier, we described how the Aruban geological formation has undergone tectonic *displacement, uplifting, sea level rises, and deformation activities*. Subterranean *temperature and pressure* regimes during its formation caused distinct differences between rocks in *morphology*, *mineral composition* and *physico-chemical characteristics*. These differences in resistance against the influences from sea, sun, wind and rain have shaped the relief patterns in the Aruban landscape as we know it today. We describe some of these relief patterns in the ALF/Batholith complex and Pleistocene terrace landscape and explain how processes of *erosion, weathering* and *sedimentation* created new opportunities for soil development and vegetation (Finkel & Finkel, 1975).

Watershed and Salt Spray Park

Interestingly, because of the elevated topography at the windward side, the *central watershed line*[19] (Figure 6) is at a close distance of only 0.6 km from the Northeast coastline and up to approximately 4 km from the Southeast coastline. With the exception of the more central area, the watershed line roughly defines the border of an intended *Salt Spray Park* that is envisioned to protect and cover the relatively still untouched natural environment along the Northeastern coastline (DIP, 2009). In the North and in the South, the watershed areas east of the *central watershed line* have little or no history in agricultural activity[20] and are still sparsely inhabited today. Current housing projects, however, develop beyond former agricultural terrain and advance towards the Northeastern coastal zone.

[18] www.meteo.aw

[19] The watershed is an imaginary line that separates one drainage basin from another one. A drainage basin or catchment area covers the total land area that is drained by a single (dry-) river system.

[20] For information on the original agricultural extent in 1911, we refer to another paper in this landscape series (Derix R., 2016d).

The east coastal *Salt Spray* area is still characterized by nearly total absence of urban-based pollution in terms of contaminated rainwater runoff, sewage water, surface water, or even groundwater. The planning of a *Salt Spray Park* is, therefore, a unique opportunity to create a protected environment that stands in direct relation to the marine ecosystem along the Northeastern coast and the prospected *National Marine Park*. Besides, the area is still 'pristine' and offers the potential to enhance sustainable tourism.

More centrally along the Northeast coastline however, was quite some agricultural development in early 20th century. These Batholith soils are located east of the main watershed line, but are still protected from the salt-laden winds by for instance the hills of the Aruba Lava Formation (ALF) and the the Gabbro Formation ('Seroe Crystal' and 'Seroe Plat'). Today, the region has turned into new housing projects and economic activity, like most of the former agricultural lands. Consequential to the respective locations of these residential and economic activities there will be some degree of 'polluted' surface- and groundwater run-off east of the central watershed line into the coastal areas.

Figure 5 The map shows the main watershed line (red colored line) that delineates the rainwater catchment divide between southwest and northeast. The dry-river systems are not visualized in the map. The small plots (brown delineated light-colored plots) and the large plots (arced) represent respectively the areas where mixed agriculture and Aloe cultivation took place in 1911 (Werbata, 1913)

The different colors in the background represent different geological formations (from north to south respectively, the Aruba Batholith, the Gabbro Formation, the hills of the Aruba Lava Formation, the Limestone Formation and alluvial soils). Beach sands, beach rock and ramparts along the coast are not shown.

Figure 5 shows that the agricultural landscape in early 20th century is confined mainly to the areas west of the main watershed line, on the undulating quartz-dioritic soils of the Aruba Batholith and on the alluvial mud and sands of the dry-river systems at the Southwest coast.
Aloe production took place along the Southwest coast, on the Lower and Middle Limestone Terraces, but not immediately next to the sea.
A sharp demarcation reveals where agricultural subsistence in early 20th century situates that is in large *defined by the geology of the substrate* (Derix, 2016d). Today, these areas have largely been parceled and transformed into housing and economic development projects.

Differences in the drainage pattern of dry-river beds

Differences in chemical composition and resistance against weathering and erosion have in large determined the drainage pattern of dry-rivers (Finkel & Finkel, 1975). The location of these seasonal dry-gullies, better called *dry-rivers* or 'rooien' (in Dutch) is often defined by the location of the fracture lines and deep *geological faults* (see Figure 1).

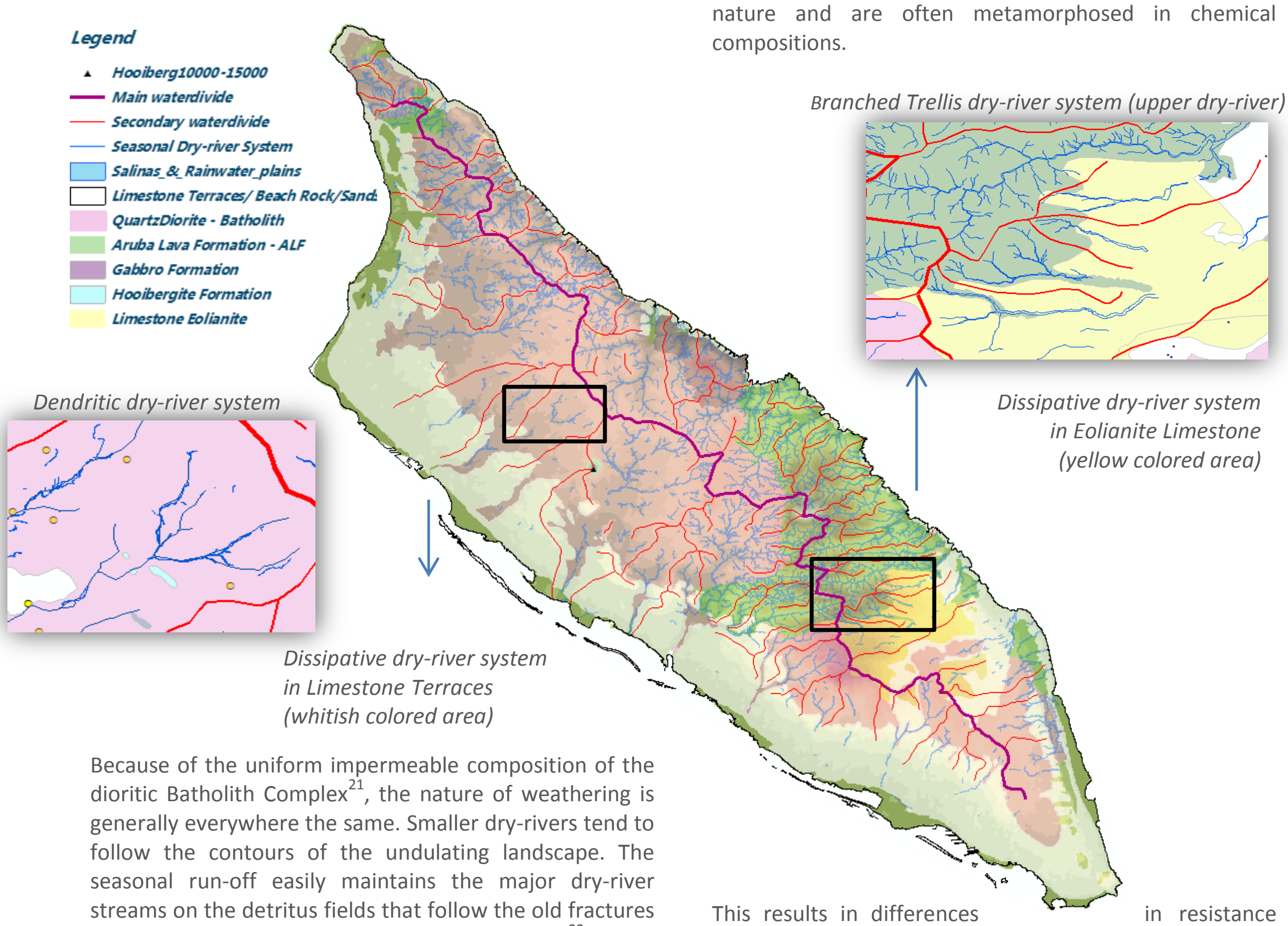
Limestone Terraces

On the *Limestone Terraces* the main dry-rivers have carved up to the hard bedrock or sand and clay layers underneath the thick limestone layer and show little or no branching. Already in Pleistocene, during periods of sea level low stand, drainage systems created the deep cuts in the limestone coast that end in the small bays (locally called 'Boca's'); that still exist today. Limestone is highly permeable and the terraces are easily eroded. This is also why the watershed lines can only partially be determined in the Limestone landscape (Figure 5 and 6).
We observe few branches of dry-rivers on the Limestone Terraces.
The smaller run-offs disappear underground. There is little surface water and the majority of rainwater drains straight into the cracks of the porous limestone into the groundwater. Interestingly, despite the high permeability of limestone, trees in these areas seem to suffer less from periods of drought compared to the trees on the crystalline rock in the batholith. The cracks and cavities of the Limestone are filled with soils that consequently show a higher water-retention capacity than the upper soil layers on the semi-impermeable Batholith. The trees on the Limestone have the ability to reach these ground water sources during the dry-season (De Freitas, Nijhof, Rojer, & Debrot, 2005).

Batholith

In the *heavily weathered Batholith*, the pattern of the dry-river streams is *dendritic in nature (pers. comm. A. Curet, Figure 6)*. Most of the Batholith consists of a low rising and falling landscape with islands of naked impermeable rock amidst a thick layer of erosion breakdown material.

Figure 6 Hydrological features in the Aruban landscape



Because of the uniform impermeable composition of the dioritic Batholith Complex[21], the nature of weathering is generally everywhere the same. Smaller dry-rivers tend to follow the contours of the undulating landscape. The seasonal run-off easily maintains the major dry-river streams on the detritus fields that follow the old fractures and faults by the movements of the upper crust[22]. These major dry-rivers may carve deep as there is little resistance against erosion in these weathered parts of the crystalline rock (Finkel & Finkel, 1975).

Gabbro Formation (area of Seroe Crystal)

The Gabbro rocks are even more resistant against weathering and remain somewhat elevated in the landscape. In essence, the process of weathering and erosion, however, is similar as in the dioritic Batholith.

Aruba Lava Formation (ALF)

In contrast, the dry-rivers in the *Aruba Lava Formation* are strongly branched under a variety of often right angles[23] (Figure 6). This is a direct consequence of the different characteristics in physical weathering of the *basalt-based* rock (ALF) in comparison to the *quartz-dioritic/gabbro* rock (Batholith).
The rock formations in the Alf region are less uniform in nature and are often metamorphosed in chemical compositions.

This results in differences in resistance against weathering. In combination with the east-west orientation of many faults and dykes parallel ridges of resisting rock and resulted in a distinct pattern of the dry-river seasonal run-offs, a so-called *trellis pattern; pers. comm. A. Curet*.. Once carved, beddings of hard rock remain that lack the fertile soils as we find in the Batholith. The dry-rivers that carry sediments from the ALF are generally shallow and lack any good soils for agriculture (Finkel & Finkel, 1975).

Tanki's and Aquifers in the Batholith

Because of the low infiltration rate of the rock substrate and high coefficient of runoff (Finkel & Finkel, 1975) the Batholith is well suitable to catch surface rainwater. In the mid-20th century artificial wells and reservoirs or rainwater dams (Tanki) were constructed in the Batholith region specifically for agricultural purposes, to irrigate the fields, and even for domestic purposes (Grontmy & Sogreah, 1968).

[21] The Batholith is differentiated in a wide variety of crystalline rocks but the time of solidification of the magma after eruption was too fast to enable crystallization into different rock types.
[22] The thrust and slide-slip faults cut the later Batholith intrusion occasionally up to the surface.

23 'Trellised drainage patterns tend to develop where there is strong structural control upon streams because of geology' www.physicalgeography.net/fundamentals

Subsurface infiltration of the otherwise impermeable rocks occurs along the fault lines and the smaller fractures and cracks (Finkel & Finkel, 1975). Isolated shallow wells exist that each have their own water regime, based on the local hydraulic characteristics of the weathered zone. Small aquifers exist near the barrier where the Limestone Terrace layer meets the (underlying) hard Batholith rock and where the rainwater that easily seeps through the highly permeable limestone may get blocked by the harder rock and accumulates. In the early 20th century, water from small aquifers in the Batholith rocks was intensively exploited by man-dug holes and drilled wells (see also Derix R., 2016d). A natural freshwater spring exists in Fontein (at *Boca Prins*, see Figure 5) and derives its freshwater from a small local Limestone outcrop at the end of a large fracture in the hard rock bedding that also carries a dry-river 'Rooi Prins'.

Groundwater

Today, drinking water is industrially manufactured at the Balashi water production facility WEB[24] NV. But in the past, besides the seasonal water from man-made surface rainwater reservoirs (tanki's) or from man-build rainwater cisterns directly at the house, freshwater was retrieved from groundwater accumulations via drilled or man-dug wells[25] or directly from the freshwater spring in Fontein.

The wells that are situated in the Batholith or near the border with the limestone, generally tap from aquifers that are situated deep into the ground or directly from the groundwater. As argued already, the Batholith and Aruba Lava Formation consist of hard impermeable rock, and meteoric water (water that originates from precipitation) can only seep into the ground along subterranean fracture lines (i.e. faults) or can accumulate in the deep pockets where the rock is already heavily weathered. Also, underneath the deep beds of detritus and clay and sand particles, as occurs in some dry-river beds, water can accumulate on the deep impermeable rock. The composition of groundwater is generally brackish and influenced by the type of rock in the dry-river catchment-drainage basin. The wells that are situated more to the coast tap from the limestone aquifers and are easily polluted with seawater. When the pumping of well water is too intense, infiltration and mixing with seawater occurs and the water becomes too brackish even for agricultural use. A study by Sambeek, Eggenkamp and Vissers (2000) shows that the salinity of the groundwater in Aruba is high compared to neighboring islands. The authors also found that in only a *third of the wells* in Aruba (n=33), the water was suitable for irrigation purposes, as there is a risk on salinization of the land and a negative effect from the well-water's high sodium concentration that might influence the physical soil structure as well. Nonetheless, most of the well-water is still usable as drinking water for livestock.

[24] www.webaruba.com

[25] Today, the water we consume is from imported bottles or from the water produced by the local Desalinization Plant (Web Aruba).

Chemical and Physical weathering

Weathering of the rock material in the *Batholith* differs from the *Aruba Lava Formation* and the *Limestone Terraces*. Processes of physical and chemical weathering and erosion followed on each other differently. In general, under semi-arid conditions, soils are only infrequently moist and (chemical) weathering conditions are slow, which also limits the formation of rich soils.

Weathering in the Limestone Terraces

The most suitable soil formation for agriculture, in the *Limestone Terrace areas*, occurs only in dry-river beddings. Limestone, namely, does not weather down into soil, but consolidates and lithifies under wet conditions and may after dissolution and recrystallization of the carbonate components, easily wash away. Soil formation, however, does take place in the dry-river beddings in Limestone areas as these generally also carry mud, organic compounds, clay, and erosion remains of upstream rocks in the catchment-area (de Vries, 2000).
Accordingly, the seasonal dry river streams have easily cut through the permeable Limestone Terraces and have created fertile valleys where they open into the sea. Their sediments are high in carbonate content and contain mineral elements from the geological composition of the catchment-area (van den Oever, 2000). These dry-river beds contain relatively deep alluvial soils and have favorable hydrological conditions for agriculture (Finkel & Finkel, 1975). The maps in figure 2 and 5 respectively show the location of the alluvial mud and sand sediments and the areas, in particular near the southwest coast, that have been used most intensely for agricultural purpose in early 20th century. Historically, these dry-rivers often come with small bays and inlets that offer habitat for a number of plant (mangroves, etc.) and animal species (bird protection areas).

Pressure release, expansion cracks and weathering in the Batholith rocks

The solidification in Late Cretaceous of the Tonalite and Gabbro Batholith took place deep in the earth crust under high pressure and temperature regimes followed by a long period of cooling that has resulted in a homogeneous crystallization of the intruded rock material. Initial strain and ruptures took place deep under the earth surface as a result from physical stresses. The faults, dykes and veins that we can observe on the earth surface are the results of such processes and date back from early orogenesis[26].
In time, however, erosion of the top sediment layers exposed the Batholith rocks. With the removal of the mass on top there and consequent pressure release, more expansion cracks developed along relaxation and distension joints.
When water is able to infiltrate deep underground along the fault lines in the cracks and joints, processes of chemical weathering can take place.
Tonalite is high in silicate content and in contact with water hydrolysis takes place at the electrically charged crystal surfaces. This is a form of *chemical weathering* that

[26] The process of mountain formation by deformation of the Earth's crust

typically developed in the past in Aruba, when there were more humid and wet conditions than at present (Herweijer, 1979) and when rainwater was able to infiltrate inside the joints, deep in the rock underneath the surface (STINAPA, 1977)[27]. As the chemical weathering[28] continues, the disintegration of the rock material takes place. Joints turn into cracks and blocks of rock develop in a cube-like shape (typical for the joints in Granite or Quarts-Diorite rock). The chemical surface weathering is of course most intense at the edges and corners of the rocks (where the surface to volume ratio is largest). The result of the differential weathering is a boulder shape rock formation, as if they were placed and carved carefully to fit on top of each other. This type of weathering, however, takes place only as long as humidity (within the soil) is in direct contact with the rock. Once the 'rounded' Tonalite boulders surface, the loose weathered material in the cracks is taken by erosion. This explains why the rounded Diorite boulders have this shape and why they are still seen in large accumulations in the Aruban Batholith landscape. After exposure at the surface, the conditions, namely, turn too dry for chemical weathering and the further disintegration of the rock material takes place physically and under the influence of the sun.

Physical weathering

In the absence of water, most weathering in semi-arid environments is physical in nature. Rocks are bad heat conductors, but the alternation of intense heating during the day and cooling at night, in particular in combination with the alternation of wet and dry seasons, enables some level of physical weathering even at the hardest rock surface.

Sheeting of rock

The solar heat reaches up to millimeter or sometimes centimeters level deep into the rock. Different minerals expand differently when heated and, thus, under the influence of solar heat expansion cracks occur parallel to the rock surface. The daily sequence of expansion at day and contraction at night attacks the rock from all sides, but again, like is the case with chemical weathering, the strongest physical weathering occurs at the outer sharp edges where the surface to volume ratio is largest. Because of the homogeneity of the quartz-diorite rock components these rocks tend to peel off in time, layer by layer.

This process is called 'rock foliation' and creates an even more "spheroidal" appearance of the tonalite rocks. Due to the fact that some rocks still have a somewhat higher resistance against weathering than the remainder of the Batholith landscape, the final stage is an undulating landscape, typical for the Aruban Batholith with some accumulations of large rounded exfoliated Tonalite boulders.

In contrast, the rocks in the Aruba Lava Formation are more divers in the nature of composed material and tend to break apart piece by piece.

Stream sediments

Rainwater is only seasonally available and, therefore, most of the detritus and sediments remain largely unaltered in mineral composition at the surface. As a result of the accumulation of rainwater with humus and humic acids in cracks and crevices and in the dry river beds, some organic weathering and soil formation is manifested in these locations. Shallow soil is sufficient to provide new opportunities for vegetation that will accelerate rock decay and create even better conditions for soil formation. The hard and impenetrable rocks in the beddings of the seasonal streams in the Batholith only allow small puddles of water, however, where little organic compounds can collect and turn into soil.

A baseline study carried out in 2000 (van den Oever, 2000) shows that the stream sediments in the quartz-diorite Batholith are mainly *acidic in nature*. They have high silicate content, but are depleted of most metal elements and consequently offer relatively poor soils for agriculture. The Gabbro dry-river sediments have more metal ions and somewhat better soils, but the highest concentrations of metal elements are found in the ALF region. The hard rocks of the ALF, however, offer little opportunity for agriculture.

The dry-rivers that origin in the ALF region and end at the Northeast coast have almost no extent and have relatively narrow beddings. Those that have their downstream southwestwards, however, have large beddings that reflect the rich geology of their wider drainage basin and do provide relatively good soils for agriculture (see also Figure 2, 5 and 6) (Grontmy and Sogreah, 1967).

The interplay between hydrogeology, soil formation, climatic conditions and vegetation growth is elegantly portrayed by De Vries in Curacao (2000) and Van Den Oever in Aruba (2000). Even at some distance from the coast, under the harsh semi-arid local conditions, salt accumulation is likely to occur in the topsoil layers, influenced by the salt-laden Passat winds (de Vries, 2000). This process is called 'salinization'[29] and occurs when evaporation exceeds precipitation and the concentrations of soluble salts (sulphates and chloride of calcium, magnesium, sodium and potassium) in the upper soil layer increase until these eventually precipitate.

Today's influences on soil and groundwater

The deposition of weathered material is relevant for the formation of soils and delivers the nutrients for plant growth. However, it is not merely the type of parental material of the substrate from the watershed hinterland that determines the quality of the soil. Climatic conditions, local topology, vegetation type, human action, and also the presence (or allowance) of small insect fauna, etc., play a role in the process of soil formation.

[27] Reference made in De Vries (2000).

[28] Chemical weathering in contrast to physical weathering involves an alteration of the chemical and mineralogical composition of the rock material.

[29] Salinization will of course also be the case where salt spray accumulates and rainwater drain is limited. Under specific mineralogical conditions on the more calcareous grounds the same process is called 'calcification', i.e. when the accumulation and of precipitation involves calcium carbonate (CaCO3).

Much topsoil have been washed away in Aruba already by seasonal rains or blown away by the trade winds after men exploited and the sun baked the land. Deforestation, overgrazing, and land clearances all had their impact. Loss of valuable soils we find elsewhere in the Caribbean (Ramjohn, Murphy, Burton, & Lugo, 2012) and worldwide (Howgego, 2015). In the mid-17th century large numbers of goats and sheep were free to roam and graze the land. The harvest of woods was already severe and was to continue for over three centuries in total (Hartog, 1953). In earlier century written accounts, the Aruban countryside is referred to as harsh, barren without much vegetation and with little or no topsoil (Teenstra, 1836).
Today, in many 'wildered' spots, we still find evidence of intense erosion, where the land has been cleared (or grazed), and nothing was put in place to retain the water or prevent the loss of valuable soils.

Photo: Ruud Derix, Sept 2015.

Soil enrichment and pollution in (sub) urban areas

Inside today's walled perimeters of the new densely inhabited areas new opportunities arise for soil formation, as these walls not only prevent a rapid rainwater runoff from the home gardens (or hotels, etc.) but also ease the accumulation of plant detritus in the garden enclosure. New (garden) ecosystems develop, sometimes added with irrigation during the dry season or with additional fertilization, albeit that the garden vegetation is frequently more exotic in nature with changed opportunities for local flora and fauna (Barendsen, 2008) (van Buurt & Debrot, 2012) (van der Burg, de Freitas, Debrot, & Lotz, 2012) (Maunder, et al., 2008).
The situation outside the landscaped garden environments can be completely different. Some urban areas may experience an increase in the incidence of flooding and sedimentation after heavy rains (Derix, 2016f) whereas in other places soil erosion is intense due to a rapid channeling of the rainwater runoff via the draining infrastructures. In particular when uninhabited land is 'cleared' for new construction (i.e. removal of 'wild' vegetation including topsoil layers with excavators) valuable soils are easily carried away (RuG/VROM, 2000). This is particularly the case during the rainy season (Perk, 2003).

As the suburbanization of the landscape[30] progresses, pollution from human activities plays a more important damaging role as well and influences the face of the landscape. Enriched soils not only provide more optimal circumstances for plant growth, but also may create new habitats where invasive species flourish best. The continual nutrient enrichment is also thought to have long-term consequences on the quality of ground- and surface waters and may even influence the marine ecosystems negatively via groundwater and surface water runoff (Cable, Corbett, & Walsh, 2002) (Day, 2010).
Besides from excessive fertilization of garden soils, additional contamination of soils, ground- and surface waters comes from the effluent of household sewage from shallow surface cesspools[31], the use of herbicides, pesticides, and alike, as well as the disposal of detergents and other discharges (Finkel & Finkel, 1975). These effectors accumulate in residential soils and are partly carried away with the seasonal rainwater runoff into the marine environment. Possibly phosphate (Sharpley, Daniel, Pote, & Sims, 1996) and more likely nitrogen enrichment (Cable, Corbett, & Walsh, 2002), and certainly chemical pollutants thus create a threat, not only to the local surface- and groundwater and freshwater in wells, but more importantly to the reef ecosystems[32] (Buurt, 2008). Coral bleaching and algal blooms along the coast have been described in other parts of the Caribbean already (Gast, 1998) and are a potential threat in Aruba as well that may even affect the tourism industry (Goreau & Thacker, 1994).

In conclusion

In this paper we have made an effort to summarize and show how geological and (paleo) climate events have set the boundaries for the natural development of the landscape. Today's suburban developments create a new type of landscape and habitat that differs as it tends to become more detached from its 'natural' settings. An overall loss in nature surface area and a human-induced impact on the local environment created a *multifaceted challenge for the prospected sustainable economy*. A good understanding of past history is significant to focus on the right efforts.
Weathering, erosion, soil formation, and the subsurface mixing and flow of fresh and marine waters is a continuous process and is active today as it was in the past. Changes on land indirectly influence the processes at sea, in particular in a small island setting when processes of eutrophication and contamination of ground- and surface waters occur. We must understand that the dynamics on land and at sea are inseparable. It is important to recognize the detail of spatial events as today's local events are in interplay with the geological formations of the landscape. The modern impacts and the challenges that we face will be different in different regions. In this paper we have made an attempt to help understand where these differences may be relevant and what these differences may include.

[30] We refer to a more detailed account in this series' paper No. 4, 'The suburbanization of the Aruban landscape' (Derix, 2016d).

[31] For a more detailed account of the location of household cesspools and public sewage systems we refer to this landscape series, paper No. 5 'Conflicts between the Economy and the Landscape in Aruba'

[32] An overview is presented by G. van Buurt during the WildAruba meeting in 2008, in Aruba: 'Nutrients on Coral Reefs', www.wildaruba.org.

Endnote:

Cretaceous 145-65 Mya
Ends with the extinction of dinosaurs

Paleogene 65-24 Mya
Evolution of first small mammals and birds

Early Neogene 24 Mya -1.8 Mya
First evolution of ape and man species

Quaternary Pleistocene 1.8 Mya - 11.000 year
Lasts until the latest Ice-age and is the time of saber-toothed cats, dire wolves, mammoths and stone-age man.

Quaternary Holocene 11.000 year – today
Man gatherer/hunting lifestyle turn to farming and the domestication of animals.

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Landscape series: 4

The suburbanization of the Aruban landscape

The Aruban landscape has undergone many changes in history. This paper is part of the landscape series:
"Spatial Developments in the Aruban Landscape: A multidisciplinary GIS-based approach derived from geologic, historic, economic and housing information"

2016

"We must spare no effort to free all of humanity, and above all our children and grandchildren, from the threat of living on a planet irredeemably spoilt by human activities, and whose resources would no longer be sufficient for their needs".
—United Nations Millennium Declaration (2000) —

Contents

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We like to thank our colleagues at the CBS for their comments on the manuscript.
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This paper is part of a series on the developments that relate to the Aruban landscape. To bring perspective to current environmental threats and developments good knowledge of present, but also of past spatial processes is vital.
We show in this paper how the extent of early 20th century Cunucu landscape in Aruba followed the contours of the geological substrate and past human action and how these agricultural developments shaped the layout of today's trends in suburbanization. We will go into detail and explain the shift in the location of new construction and infrastructure over the last hundred years. In an example we explain how some geological and past topographical features have influenced the development of infrastructure and housing today.

This study is also an example of how we can use GIS[1] methodology to study spatiotemporal patterns in combination with the use of historic maps in Aruba. The aim of this study is to inform and give insight in the long-term consequences of change. A more general aspect of this study is to help us grasp a larger perspective and learn to comprehend, similar to what we describe in this study, how current change in nature and habitats will define the future opportunities to exploit the landscape and its intrinsic values.

The historical perspective

The changes in the landscape over the last century went at a very fast pace. At the end of the 19th century, the landscape was already characterized by quite open panoramas (Teenstra, 1837) due to over two centuries of intense harvest of woods and grazing by herds (Hartog, 1953). In late 19th century, following new impulses to the economy, initiatives were taken to stimulate agricultural subsistence (Ridderstaat, 2007). Several cultivation projects took place on the more fertile soils in the land interior (San Barbola) and on the more nutrient-rich fluvial beddings near the coast (Savaneta). Consequential to the success of these projects (Alofs, 2015, pers. com), in just a few decades, at the turn of the 20th century, most of the 'arable' land was already developed for mixed farming and Aloe cultivation (Werbata, 1913). The exploitation of the Aruban countryside by farming, the breeding of goats, sheep, poultry, pigs and cattle and the cultivation of a variety of (local) vegetables and fruits, lasted for over half a century. The typical countryside with open panorama's, grazing livestock and farmland improved local living conditions considerably and is passionately called the *Aruban Cunucu*. The climatic circumstances and poor soil conditions made agricultural subsistence harsh, however.

Following the discovery of large oil fields in neighboring Venezuela, the oil processing industry was introduced in Aruba. Soon after each other, in about 1929, two oil refinery installations were accomplished, one in San Nicolas and one near Oranjestad. To make both ends meet, it was already common that, seasonally, Aruban farmers would leave their fields and went to work abroad, for instance to assist in the harvest of sugarcane in Cuba or in Venezuela. But with the new opportunities in the upcoming industries, the economic prospects of Aruban farmers changed as well. Soon farmers decided to leave their traditional agricultural subsistence and either went to work abroad or in the oil refineries of San Nicolas and Oranjestad. In the years that followed, and in particular during World War II, a service- and facilitation-industry developed in Aruba as more immigrant workers from neighboring Caribbean Islands had come to work and stay in Aruba. With the growth of the economic developments in Aruba, the number of workers in agriculture went down from an initial 1,281 agricultural livelihoods in 1908 to 736 in 1924 (Kelly, 1999; reference in Ridderstaat, 2007, Table 4, pp 18). Actually, in 1912, 14% of total population (1,337 workers) was officially registered in agriculture (Benjamins & Snelleman, 2015). In the years that followed, crop fields were left more and more abandoned as farmers went to work in San Nicolas and Oranjestad.
Initially, the farmers' family kept the agricultural subsistence running but soon the farmland was left completely and wildered. The once well-maintained agricultural countryside and the typical Cunucu scenery with small houses and stone walled corals or cacti fences slowly disappeared. Those who could afford it exchanged their small cunucu house for the more appealing modern American-style housings (Bakker & Klooster, 2007).

The agricultural exploitation of the *Cunucu* landscape, thus, didn't last for long. In less than half a century most of the former cunucu turned into what is locally called a *Mondi*[2]. For some time, the Mondi developed in its own natural course of abandonment. Nature was at the brink of reestablishment on the open fields when the land was again in new demand, now for the housing of a growing population and the expansion of economic activities. In only a few decennia most wildered terrains became parceled and the vegetation regrowth was cleared for new construction. Today again the economic development and urbanization spreads over large parts of the island. Local nature is under pressure, once again (Barendsen, et al., 2008).

We have come to the point that a majority now realizes that we have to protect the remaining natural values (Aruba, 2011) and that there were limits in the way that growth took shape. Worldwide, the conviction has taken shape that the remaining natural environment plays an imminent role in the health of local living conditions and is important for economic development (The World Bank, 2010). A number of threats already receive regional attention as they appear to be building. Some of the major harms that are known to play a role in the deterioration of environmental health conditions are eutrophication of marine and fresh waters (Lapointe & Mallin, 2011), (Gast, 1998) (Haapkylä, Ramade, & Salvat, 2007), marine and land pollution (Bak, 1987), chemical health disrupters (EEA, 2012), exotic pests (van Buurt & Debrot, 2012), (van der Burg, de Freitas, Debrot, & Lotz, 2012), and the loss in natural habitat and landscape [(Del Nevo, 2008), (Baker, Glynn, & Riegl, 2008)].

[1] A GIS (Geographic Information System) is a computer-based tool that enables the linking of information from many different fields on the basis of a common geographic component. Layers with information from for instance, socioeconomic, environmental and topographic surveys can be brought together and analyzed on a common spatial scale. Linked in this manner, the GIS system provides additional information and opportunities for research.

[2] Wildered countryside

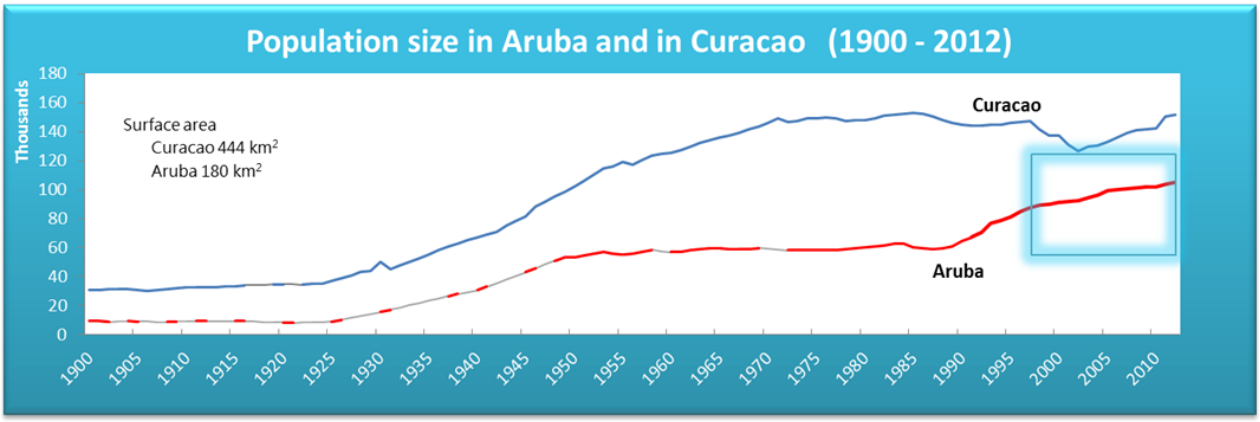


Figure 1 Comparison between population estimates in Aruba and in neighboring Curacao over the last century.

Source[3]: Population Registry Office Aruba, CBS Aruba and Curacao.

Note[4]: The period highlighted by the blue square (1998-2010) denotes the period on which further analyses is conducted for the purpose of this paper. To make the graph visually more appealing, we added the missing data points with simple arithmetic interpolation (indicated by the gray-colored line segments).

Population growth

Between 1930 and 1950 population growth was intense due to the booming oil industry (see figure 1). After the very profitable years during WWII, the oil industry, however, had to economize its production facilities because competition was fierce. The Arend Oil Company near Oranjestad had to close its doors in 1953 and the Lago Oil refinery in San Nicolas was forced to modernize and downsize its workforce.

During the years that followed, the population size in Aruba didn't change much, up until the 80's. After many years of a stable economy but without the desired economic growth, political aspirations had taken shape to separate from the former Dutch Antilles and attain a financial as well as administrative equal political position within the Dutch Kingdom. In 1986, Aruba became an independent state within the Dutch Kingdom under the so-called '*Status Aparte'* (Alofs L. , 2006).

Meanwhile, driven by the economic progress in Europe and the US, a tourism industry developed that offered new opportunities in the region. A growing number of travelers in Europe had money and interest to explore and visit the Dutch territories west of the Atlantic. With the boom in the tourism industry, drastic changes took place in the landscape. The face of coastal regions changed with the construction of Hotels, a facilitation industry and many residential areas to house the new immigrant workers. Population numbers grew once again drastically in Aruba.

In just a single century, the number of inhabitants ten-folded from about *9.700* in 1900 to *91,064* in 2000. After the first period of growth after WW II, in 1948, the population was estimated at *51,110* inhabitants. Then, after a period of stagnated economic and population growth, from the 90s onwards, the population numbers almost doubled in nearly three decades (from a short-term low of *58,873* inhabitants in 1987 to an estimated *110,108* in 2015).

Subsequent Census records show a population growth from *56,910* in 1960, *58,189* in 1972 to *60,866* individuals in 1981. The second impetus in growth started in the late 80s. Census records counted *67,382* persons during the 1991 Census, *91,064* in 2000 and *101,918* persons in 2010. Population growth continued until this day (Figure 1).

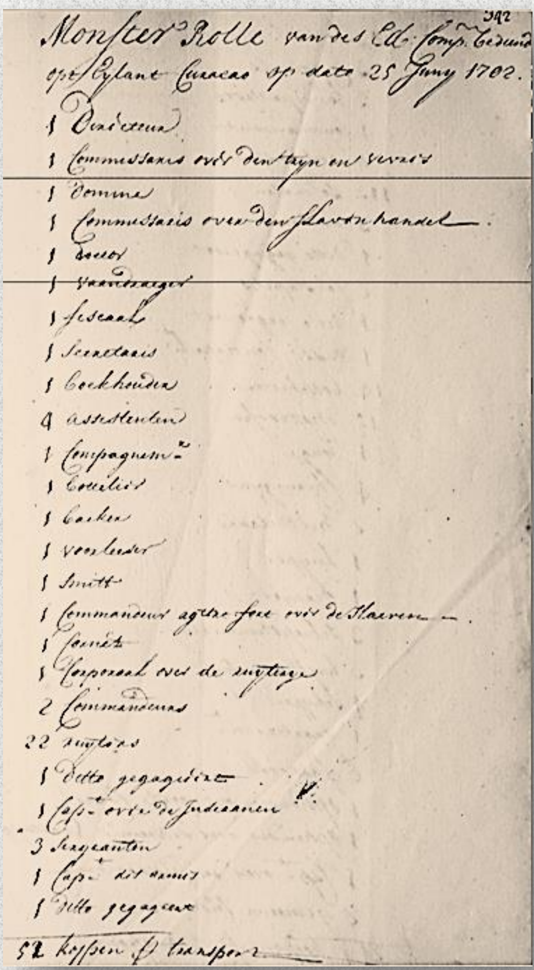
The consequences of the unremitting population growth reveal themselves in the landscape and influence the local living conditions of the small island community. An unbalanced fragmentation and loss of typical habitats and species will pose a challenge for socio-economic developments, however (EEA, Landscape fragmentation in Europe, 2011).

From the start of civilization, the Aruban landscape had transformed from a mostly wooded landscape (Hartog, 1953) into its current state of *suburban sprawl*. But strong data about the situation in the past and the changes up to now are lacking and can only be derived from incidental reports and former historic maps.

We review the more recent changes in the economy and the home living conditions in the next section, and discuss a number of indicators that are common to describe the economy. This is possible, as from 1998 onwards a well-established system with annually comparable statistical data reports exists. So, we used the year 1998 as the reference year for the description of subsequent changes from then on.

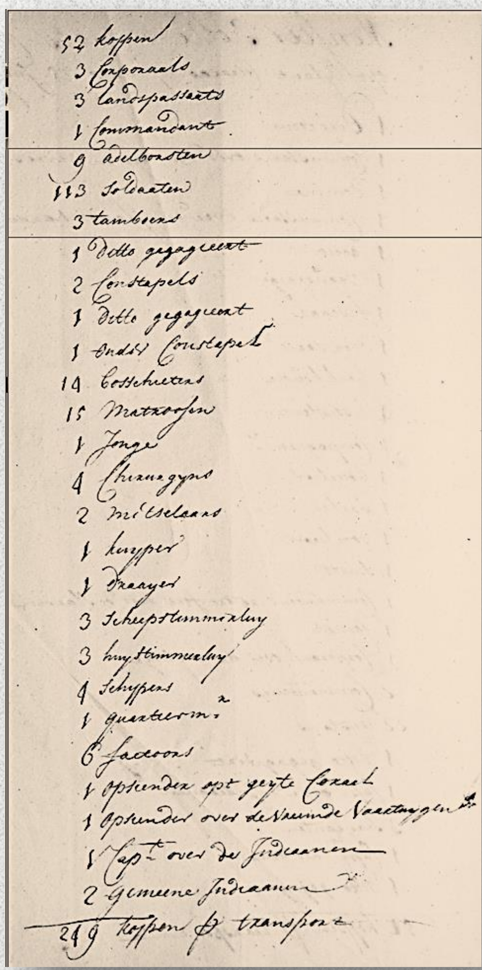
[3] The data of 1900, 1904, 1908-1911 is from: Herman Daniël Benjamins en Joh. F. Snelleman, '*Encyclopaedie van Nederlandsch West-Indië*'. Martinus Nijhoff/E.J. Brill, Den Haag/Leiden 1914-1917; Source in: www.dbnl.org (Digitale Bibliotheek voor de Nederlandse Letteren) under the auspices of the National Library of the Netherlands (Koninklijke Bibliotheek).

[4] In 1702, WIC documents mention only 5 colonists in Aruba, respectively 1 commander, 2 nurses and 2 soldiers (see the scanned documentation in Photo Series 1, pp. 5). There are no records about how many natives lived on the island at the time, but there may have been only few left to herd the cattle and horses and to harvest the logwood


342

Monster Rolle van des Ed. Comp. bedienden
opt Eylant Curacao op date 25 Juny 1702.

1 Directeur
1 Commissaris over den tuyn en vivres
1 Domine
1 Commissaris over den slavenhandel
1 doctor
1 vaendraeger
1 fiscael
1 Secretaris
1 boeckhouder
4 assistenten
1 Compagnon
1 Cottelier
1 backer
1 voorleser
1 Smitt
1 Commandeur agter fort over de slaeven
1 Cadet
1 Corporael over de ruytrye
2 Commandeurs
22 ruyters
1 Dito gegageerde
1 Cap. over de Indiaanen
3 Sergeanten
1 Cap. d'armes
1 Dito gegageerd
52 koppen p transport


52 koppen
3 Corporaals
3 Landspassaten
1 Commandant
9 adelborsten
113 Soldaaten
3 tambours
1 Dito gegageerd
2 Constapels
1 Dito gegageerd
1 Onder Constapel
14 Bosschieters
15 Matroosen
1 Jonge
4 Chirurgijns
2 metselaars
1 kuyper
1 draayer
3 Scheepstimmerlieden
3 huystimmerlieden
4 Schippers
1 quartiermr.
6 factoors
1 opziender opt zoute Coraal
1 opziender over de Naemde Vaartuygen &c.
1 Cap. over de Indiaanen
2 Gemeene Indiaanen
249 koppen p transport

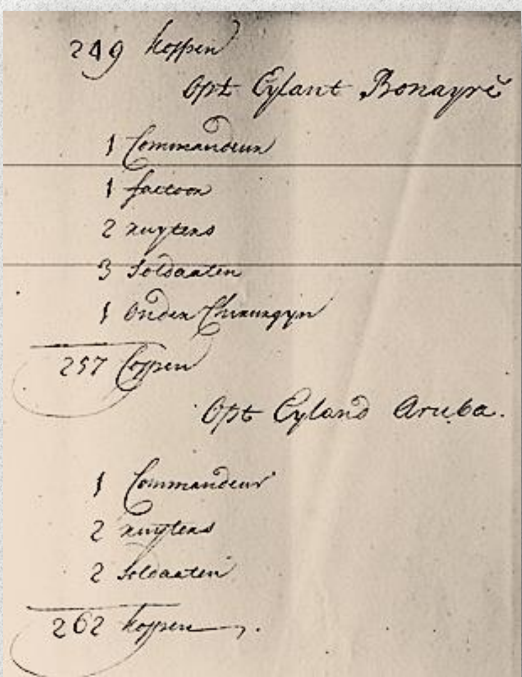

249 koppen
Opt Eylant Bonayre
1 Commandeur
1 factoor
2 ruyters
3 Soldaaten
1 Onder Chirurgijn
257 koppen
Opt Eyland Aruba.
1 Commandeur
2 ruyters
2 Soldaaten
262 koppen.

Photo series 1
First count of WIC personnel in Curacao, Aruba and Bonaire on June 25, 1702 by local WIC Commander (see next page).
Source: WIC documents of 1702 by the Cactus project www.dpp-cactus.com. Digital Preservation Project, scans v200: 342, 343. Dutch 'National Archive' under auspices of the Ministry of Education, Culture and Science in the Netherlands www.nationaalarchief.nl

Recent GDP

The GDP[5] (*gross domestic product*) is commonly used as an indicator for economic well-being and expresses the total market value of all goods and services produced in a country in a given period of time. Another measure, the *real (calculated) GDP per capita,* also takes into account the *purchase power* deflated for price increases[6]. In Figure 2 we present, relative to 1998, the population dynamics and the changes in 'real GDP per capita at constant 2010 prices' in Aruba, in between 1998 and 2013. The measure somewhat fluctuates over the years, but not dramatically, until 2009, when we observed a drastic downfall in spending capacity. Thereafter, the measure remained at a new, but lower level. Over the same course in time, the population size maintained a steady growth.

Today, the tourism industry has become the major pillar of the Aruban economy, in particular since 2012 when the Oil refinery closed its doors. Figure 3 shows that there has been a doubling in number of Cruise passengers during the final years of the last millennium, but that since then the increase in Cruise tourists has dampened and tends to fluctuate. The number of stay-over visitors also shows some fluctuation, but overall, a slow increase of 20% is observed over a 12 year period. Following the continuing expansion of the hotel and timeshare accommodations along the coast, in particular along the northwest coastline, many new establishments opened their doors. Interesting is the time period after 2007 when there was a drop in local purchasing power, yet a rise in 'Stay-over' and 'Cruise' tourists. The small economy in Aruba is dependent on the economies in large export countries and these had difficulties in maintaining progress during the years of economic crisis, in particular after 2007. It is noteworthy, that the tourism sector in Aruba gained in strength during that time, but without a rise in local purchasing power (we do recollect the closing of the Oil Refinery).

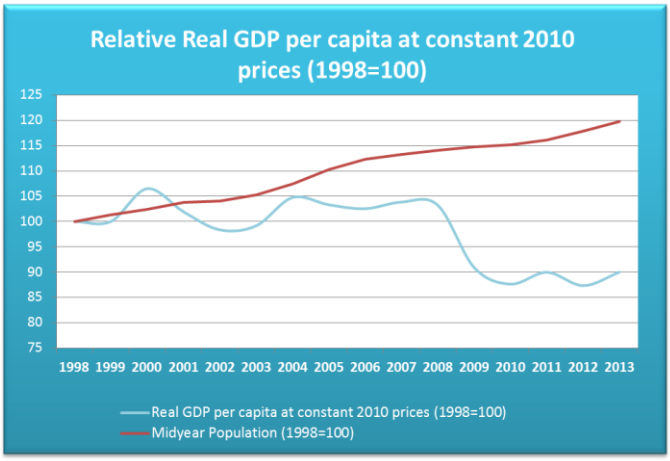


Figure 2 Development of the real GDP per capita and the midyear population in Aruba relative to base year 1998.
Source: Centrale Bank Aruba; CBS Aruba.
Note[7]: Index 1998 = 100%

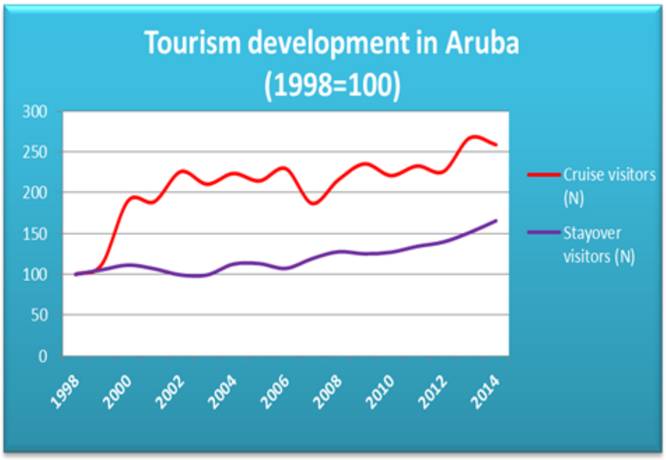


Figure 3 Development of the number of tourist visitors in Aruba in recent decades relative to base year 1998.
Source: CBS Aruba. Note: Index 1998 = 100%

Suburban sprawl and rising housing costs

The growing economy and increase in population numbers required land for the construction of houses and economic facilities. Land owners made value from this demand and readily parceled their formerly cultivated, but now wildered property lands (Ridderstaat, 2007). Large pieces of land were parceled and turned into smaller residential areas. The plots along the main roads and near the economic centers primarily deserved major interest. Thus, the countryside turned into a ribbon-like appearance of spatial developments. The transition from dispersed Cunucu houses into a ribbon-shaped spread of development along the roads is a typical first step in the process of suburbanization. This and the next phase can still be discerned on the map in figure 9.

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[5] When all products are bought and sold, total **production** should in principle equal total expenditures for consumption. The GDP can thus be calculated and represented accordingly by the consumer expenditures (all expenditure that is made through purchases) plus the investments (additional expenditure that is invested) plus the government spending, corrected for the value of exports (as these products are produced but not bought within the country) minus the value of imports (as these goods are consumed but were part of a production elsewhere)

$$GDP=Exp_C + Inv + Exp_G - Export + Import$$

Thus, the gross domestic product (GDP) includes only the goods and services produced or consumed within the geographic boundaries. If depreciation of the national capital stock is deducted from the GDP, it is called the net domestic product (NDP). If the net income from activities (production) abroad is added, it is called the gross national product (GNP). The GDP per capita is frequently used as a measure of the consumers' well-being or standard of living. The measure however requires careful interpretation when it is used to compare between countries, since it does not take into account the distribution of incomes (and these are likely to be more skewed in low income countries) nor does it take into consideration what one can get in the country for the money earned (the same products can be relatively cheap or much more expensive in one country compared to the other).

[6] Standardization of the common consumption basket between two countries is attained by using the purchasing power parity index (PPP) of a countries' currency relative to that of the other country. The correction that is used to calculate the Real GDP thus differs from the common PPP standardization.

[7] Index 1998 = 100% which means we have translated down the original graph from its position with real GDP per capita in 1998 at 114% towards 100%. The shape of the graph remains the same

The map shows the spatial extent of subsequent periods in construction. Pockets of land were originally left open behind the roads, but soon became parceled and turned into residential neighborhoods and sometimes with an enclosed network of roads (see figure 14). This is the final step in suburbanization, i.e. when the few still remaining wild pockets of land aside the build-up areas are converted as well into areas with a socio-economic purpose. This trend appears to exist in all parts of the island with the exception of the more inaccessible parts along dry-river beds and along the Northeast coast, outside the National Park (see Figure 9).

These changes are slow and may remain virtually unnoticed. With the advancement of construction, also into the more far-out regions, more and more wild or wildered spaces are about to become defragmented.

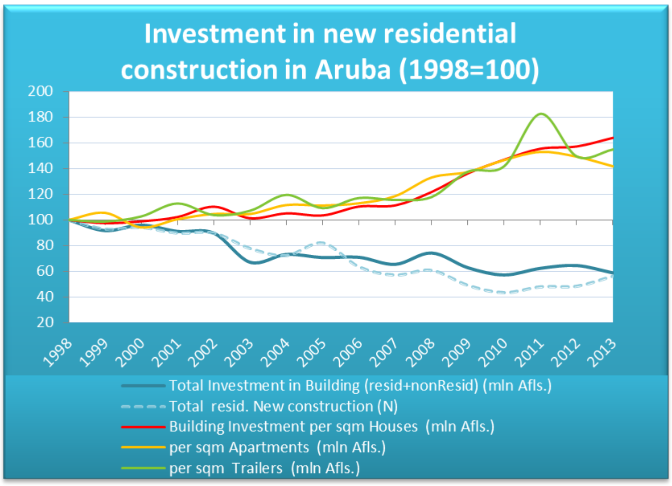


Figure 4 Frequency and investment in new construction in Aruba, relative to base year 1998,
Source: CBS Aruba.
Note: Index 1998 = 100%

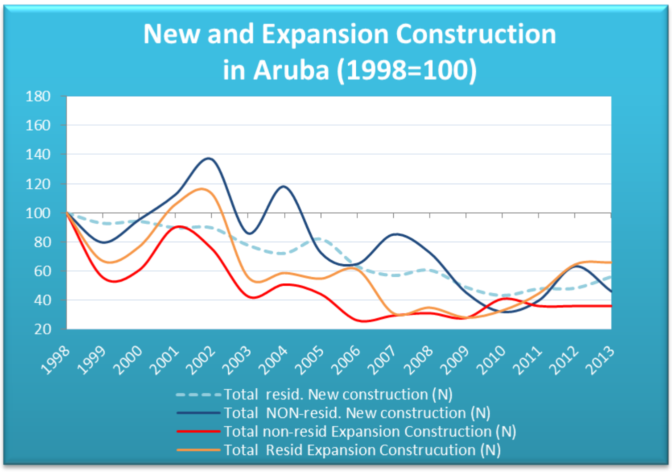


Figure 5 Frequency of new and expansion constructions during the period 1998 – 2010
Source: CBS Aruba.
Note: Index 1998 = 100%

In 1998 the peak in building applications had already passed. As of 1998 the total investment in buildings continues to drop at an almost steady rate (Figure 4). The investment per square meter of living area (for houses, trailers, and apartments) tended to increase in a similar almost steady pace until 2011 when the square meter (sqm) investment in trailers attracted incidentally and investment in apartments tended to drop. The reason for the risen interest in investment in trailers is unknown. The sqm investment in houses continues to rise. The higher investments per square meter contrasts to the lower total investment. It is apparent that the total number of new (residential) buildings is dropping, be it that in 2013 there seems to be a slight growth.

The drop in investment is not only in new construction, but also in expansion construction, residential as well as non-residential (Figure 5). The overall trend during the last decennium is downwards for 'new' and 'expansion' construction, although as of 2010, this trend seems to reverse after years of investment alternated with years of retainment. We are certain that there is much more to say about why these numbers go up and down, but in the context of this paper it suffices to reveal that there is a slowing down of construction up to 2010, but with an apparent change and increase during the years thereafter.

Nonetheless, it is important to realize that although relative to 1998 new construction is slowing down; there is still a continuing net increase in total number of constructions in Aruba.

This trend is represented in more detail in figure 6. The decrease in new construction reverses in 2010, but predominantly for residential apartments, while the yearly increase in new houses remains nearly constant.

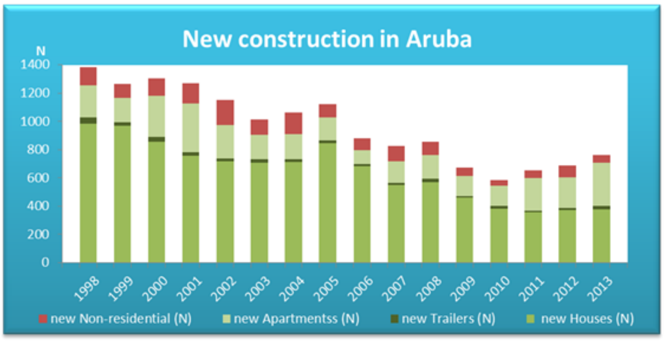


Figure 6 New constructions during the period 1998 – 2010
Source: data from DOW Aruba in Statistical Yearbook, CBS Aruba.
Note: Index 1998 = 100%

Next, we describe the situation at the beginning of the last century on the basis of the Werbata-Jonckheer map. The extent of agriculture cannot be understood without knowledge of the geological substrate (Figure 7). So, first we analyze the occurrence and extent of exploitation of the landscape at around 1911, and then we describe in detail the trends in housing developments over the last hundred years (Figure 8) with the use of GIS technology[8].

[8] A GIS (Geographic Information System) is a computer-based tool that enables the linking of information from many different fields on the basis of a common geographic component. Layers with information from for instance, socio-economic, environmental and topographic surveys can be brought together and analyzed on a common spatial scale. Linked in this manner, the GIS system provides additional information and opportunities for research.

Information derived from historic maps

Several geological maps exist in Aruba, with the focus on different geological epochs and different types of geological substrate. A number of these maps have been digitized and translated into a series of GIS[9] information layers that made a comparison of relevant spatial information possible.

The geological map of J.H. Westermann (1932) provides an initial synopsis of the geology of the island. The later map of P.H. de Busonjé (1960) and the more recent map from the 'Rijks Geologische Dienst' (Beets, 1996) provide, among other features, detailed information about the type of rock substrate of the Batholith, the Limestone Terraces and the Aruba Lava Formation[10]. We have chosen to represent information from the two more recent maps, the map from de Busonjé and the map from Beets, in conjunction with other type of local spatial information.

Information about the type and extent of agricultural land-use at its moment of climax is derived from the period 1909-1911 from the Werbata-Jonckheer map (Werbata, 1913) and is shown in overlay with the maps from Busonjé and from Beets (respectively Figure 7a and Figure 7c). Information about the height topology is also shown as background information in Figure 7b. Next, we compared the coincidence of geological substrate with the type and extent of agricultural land-use in 1911.
The information from the Werbata-Jonckheer map is used to compare the extent of industrial, housing and agricultural developments between early 20th century and early 21th century as wel (figure 8 and 9). After scanning and geo-referencing the geological and historical topographic maps, we extracted the extent of relevant features with the use of GIS Geographical Information System technology (ArcGIS v9.3.1, ESRI) and stored the information in a geodatabase for further spatial analyses.

The landscape in early 20^th^ century

The Werbata-Jonckheer map is the first detailed topological map of Aruba (Krogt, 2006) and reveals valuable information about features in the landscape of a hundred years ago. Within the scope of our current interest we visualized the location and extent of the relevant features that can be discerned on the Werbata-Jonckheer map in Figure 8.

Infrastructure

In 1911, the total road infrastructure was about 131 km, and included 79 km of road (Dutch: rijweg)[11] and 52 km of cart-track (Dutch: karreweg). A total length of 288 km footpath's connected all parts of the island.

[9] GIS technology offers the tools to integrate and compare detailed social and economic information with environmental and landscape, soil or geological information, as long as a common spatial component is available.

[10] For a better understanding of the differences between Aruba Lava Formation, Batholith and Limestone Terraces, etc., we refer to an earlier publication in this series on the landscape (Derix, 2016c)

[11] The total length of road infrastructure today is about 1,000 km

Mining

In 1879, Phosphate Limestone deposits (fossilized Guano) were first mined in Sero Colorado at the southern tip of Aruba. Phosphate exploitation was very lucrative up to WWI. A tramline ran from the Phosphate mine in Seroe Colorado to the port of San Nicolas where the phosphate was shipped to abroad.
A total of 19 separate locations on the map indicate that there was some level of gold digging at the time. The locations were situated more to the east, central and in the north, and understandably on quartz-diorite grounds.

Agriculture

Figure 7 shows the location of the enclosed grounds that are marked on the Werbata-Jonckheer map and characterized as cacti or stone-fenced agricultural terrains or more specific terrains for Aloe production. Small icons on the original map pinpoint typical natural resources, such as scattered fruit trees, but the delineation of such areas is not always obvious. The Werbata-Jonckheer map also reveals the location of a number of orchards, but without information about the kind of trees. So, aside of the description of enclosed Aloe terrains, the map doesn't provide specific spatial information about other products, such as corn, beans or any other vegetable or fruit that were common in early 20^th^ century. Neither does the map reveal information about where farm animals or free-roaming goats, sheep or pigs may be typical. Nevertheless, the map is still very informative.
For instance, the map does provide information about the road infrastructure in 1911, the water distribution system, the location of mines, wells (wind milled and otherwise), tanki's, salt pans, houses and construction material, etc.
Such information can be relevant to understand the scope and magnitude of agricultural exploitation and economic activity a century ago in comparison with today.

Windmills

It is interesting to note that at the time, in 1911, there were quite a number of wind-milled wells, in particular at a distance parallel to the northwest coastline, just east of present day Bubali Plas. Driven by the windmills of a well called '*Pos Sjon Jan',* water was transported via wells in 'Madiki' in a pipeline system to a freshwater reservoir in Rancho; one of the neighborhoods in Oranjestad. A similar pipe system existed at the Southern tip of the island, between San Nicolas and the freshwater wells in Mangel Cora, in Sero Colorado, next to Klein Lagoen (today called 'Baby Beach'). There, a few wind-milled wells drew freshwater from a large natural freshwater aquifer. The majority of wells, however, were located in the northwest.

Plantations

The Werbata-Jonckheer map also shows the location of 23 mostly small plantations with mixed agriculture, coconut trees and housings. They were generally located near the larger dry-river beddings on the 'Lower Terrace' deposit fields in the northwest, near the Frenchman Pass, in 'Dos Playa' and 'Andicuri' at the northeast coast. A single larger plantation was situated more inland, north of Oranjestad in 'San Barbola'. The 'township' Savaneta actually origins from a governmental plantation that later turned into a small village (Alofs & Romondt, 1997).

Saltpans

At some locations along the Southwestern coastline, at near sea-level on the coral/beach rock ramparts, and, in some of the salinas, located, in 1911, a total of 6 saltpan production plants:

1. Bubali Plas	4. Kas Paloma
2. Punta Brabo	5. Savaneta
3. Oranjestad	6. San Nicolas

Salt was a desired resource and shipped to abroad, but was also used locally.

The relation between geological substrate and early land-use in 1911

First, we calculated the coverage of the enclosed grounds that were mapped in 1911 as Aloe cultivation and as cacti and stone fenced agricultural land on the main geological formations (Table 1).

At the turn into the 20th century, Aloe cultivation was probably about at its height of production. The total area covered with Aloe cultivation in 1911 is calculated to be about 20.9 km^2, which covers about 11.7% of the Aruban surface area (Figures 7 and Table 1). The total area in 1911 that was covered with cacti- or stone-fenced agricultural terrains, aside from the Aloe fields, is about 37.9 km^2 and covers about 21.1% of Aruba's surface area. Thus, in total, at least 32.8% of Aruban soil was in use for agriculture.

A detailed account of the spatial extent of agriculture today is not available, but local farming is not as widespread as it was in early 20th century, based on the information from the Werbata map. Agricultural activities today confine to only a limited number of terrains.

The extent of Aloe cultivation in 1911

It is interesting to mention the sharp demarcation of Aloe fields that concurs with the delineation of limestone terraces in the southwestern coastal areas (Figures 7). The spatial concurrence of Aloe fields on the Pleistocene Limestone Terraces all along the western coast is strong and represents 88.1% of all Aloe cultivation in 1911, in contrast to 10.8% on the Batholith (Table 1 and Figure 8).

The map by Beets (Beets, Metten, & Hoogendoorn, 1996) reveals the location of alluvial muds and sands from the dry-river beddings that have cut through the Limestone Terraces and that cover part of the southwest near the coast. We have shown in figure 7 the exact location of these erosion fields that find their origin in recent Holocene, a relatively young geological time period (approx. 11.000 yrs. - today). Interestingly, the Werbata-Jonckheer map reveals that there was quite some Aloe production on these erosion fields in 1911 (7.5% of all Aloe cultivation covers about 10% of alluvial mud and sands soils), albeit that the use for agricultural exploitation other than Aloe cultivation was most typical on the alluvial mud and sand soils.

With respect to Aloe cultivation in 1911, 94.2% of the *Middle Terrace Limestone* ('MT Limestone Erosion' and the 'MT Limestone Deposit' fields) was covered for Aloe production, but only 8.3% of the *Lower Terrace Limestone*, indicating that the Lower Terrace Limestone was not the most favorable place to cultivate Aloe. Even 17.5% of the much smaller *Higher Terrace Limestone* extent was cultivated with Aloe *(Table 1)*.

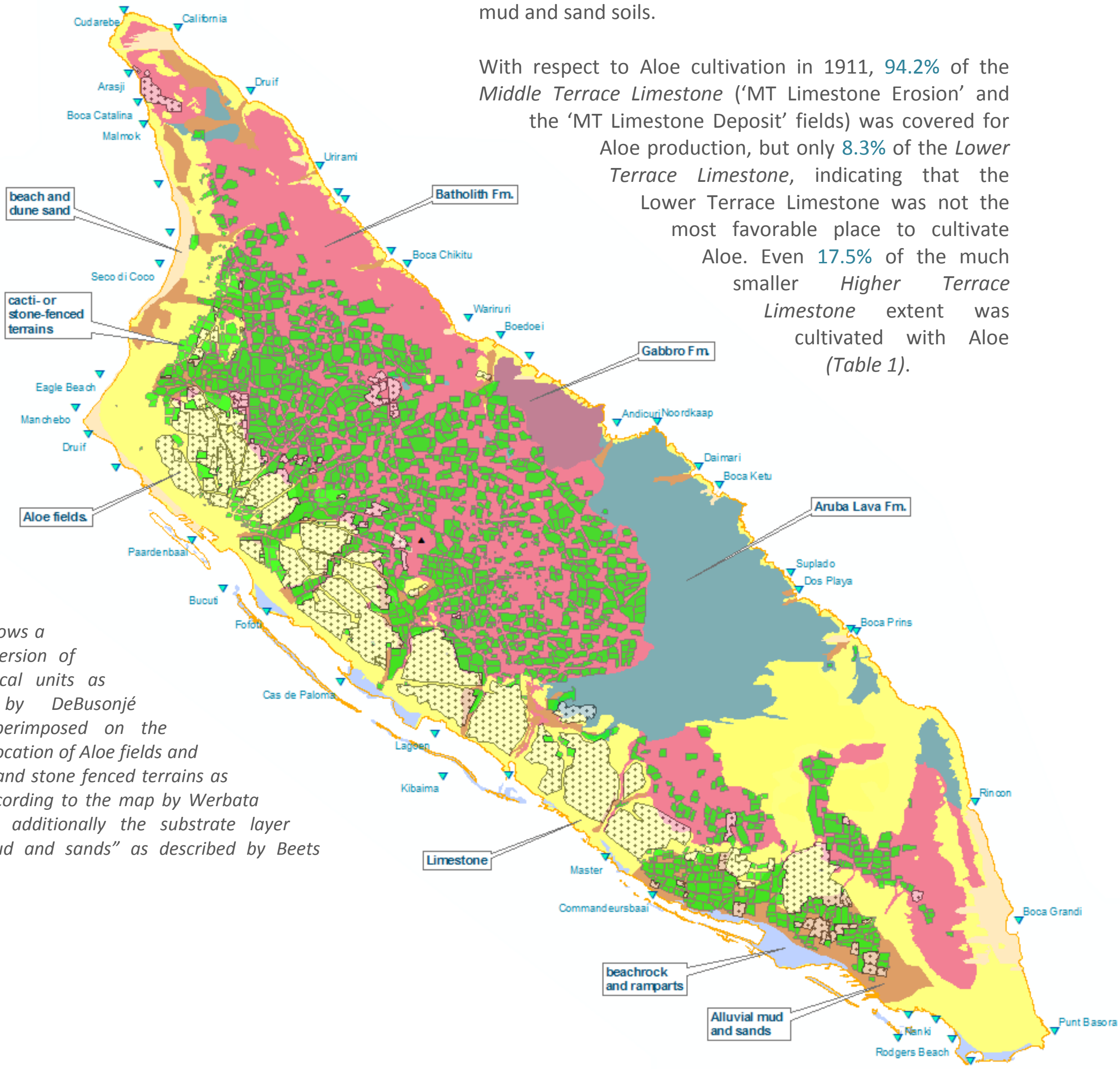


Figure 7.
The map shows a simplified version of the geological units as described by DeBusonjé (1960). Superimposed on the map is the location of Aloe fields and other cacti and stone fenced terrains as in 1911, according to the map by Werbata (1913) and additionally the substrate layer "alluvial mud and sands" as described by Beets (1996).

Total Geological Substrate cf. Busonje Map 1960 including rif islands			Aloe fields			Cacti-and stone fenced Agricultural land		
GEO Layer	total area (sq km)	% Total	total area (sq km)	% Total	% GEO layer covered by Aloe	total area (sq km)	% Total	% GEO layer covered by Agric.
ALF	23.7	*13.2*	0.2		*0.9*	0.3		*1.2*
Aruba Lava Formation Fm	**23.7**	***13.2***	**0.2**	***1.0***	*0.9*	**0.3**	***0.7***	*1.2*
QuartzDiorite	76.9	*42.9*	2.2		*2.9*	30.6		*39.8*
PhosphoLimestone	0.1	*0.1*	-		-	-		-
Limestone Eolianite	7.1	*4.0*	-		-	0.0		*0.6*
Hooibergite	0.6	*0.3*	0.0		*0.8*	0.1		*11.8*
Granite	0.1	*0.0*	0.0		*36.2*	0.0		*24.0*
Gabbro	3.4	*1.9*	-		-	0.1		*27.0*
Batholith Fm	**88.2**	***49.2***	**2.3**	***10.8***	*2.6*	**30.8**	***81.4***	*35.0*
MT	38.2	*21.3*	17.0		*94.2*	6.2		*25.0*
HT	3.1	*1.7*	0.1		*17.5*	0.0		*2.5*
LT	16.6	*9.2*	1.4		*8.3*	0.4		*2.3*
Limestone Terrace Fm.	**57.8**	***32.3***	**18.5**	***88.1***	*31.9*	**6.6**	***17.5***	*11.5*
CalcSand_Dune	4.5	*2.5*	-		-	0.1		*1.2*
(sub)recent Coral Shingle/ Bea	3.6	*2.0*	0.0		*0.1*	0.0		*0.4*
Salinas-Rainwater	1.6	*0.9*	0.0		*0.4*	0.1		*3.4*
Coastal Region	**9.7**	***5.4***	**0.0**	***0.0***	*0.1*	**0.1**	***0.3***	*1.3*
	179.3	***100***	**20.9**	***100***	***11.7***	**37.9**	***100***	***21.1***

Table 1 The listing shows subsequent geological units in Aruba and their respective surface areas as well as the amount of coverage by Aloe fields and cacti or stone fenced agricultural land in 1911. Source: Geological map from DeBusonjé (1960).

Only about 0.9% of the Aruba Lava Formation was covered with Aloe cultivation. This corresponds to about 1% of all Aloe cultivation at the time. There is also little Aloe cultivation on the Batholith and this is only limited to a few locations. One is in a single spot near Jaburibari (see Figure 7) and another concerns some scattered plots west of the Hooiberg (Meiveld, Primavera and Seroe Biento). The geological information from the maps by Westermann (1932) and De Busonjé (1974) shows that in the latter region Aloe cultivation coincided with the presence of small patches of *granite* substrate (36.2% of this granite substrate was covered with Aloe). From the Soil Potentiality Map (Grontmy De Bilt; Sogreah Grenable, 1967) we learn that the specific area in Jaburibari coincided with shallow sandy soils, but that otherwise, the area was geologically, and in soil composition not different from its surroundings. So, information from geology or soil potentiality alone is insufficient to help explain why there was a concentration of Aloe exploitation in these areas on the batholith, specifically. Otherwise, the combination of older maps (topological, geological or soil maps) proved to be a strong methodology to be able to recognize patterns in the land use that concur with patterns in spatial information; in this case, information about the geological substrate.

The extent of agriculture in 1911

In 1911, 81.4% of all the cacti or stone fenced terrains that were used for agricultural exploitation other than for Aloe cultivation were on the *Aruba Batholith,* and they covered *39.8% of all the Quartz Diorite* substrate (Table 1 and Figure 8). *Similar agriculture terrains cover* respectively *27%* of *the Gabbro* substrate and *24% of* the dispersed pockets of substrate with *Granite* rock. But, also *17.4%* of this agricultural extent was situated on *Limestone* substrate of which the majority was situated on the Middle Terrace Limestone Deposits (Derix, 2016c).

This specific area covers predominantly the region of current-day Savaneta in the southwest (Figure 7). As mentioned previously, in the region Savaneta the soil substrate is different as it contains on top of the Limestone Terrace much alluvial mud and sands (Beets, Metten, & Hoogendoorn, 1996). The area with alluvial mud and sands coincides almost completely with the spatial extent of agricultural exploitation in this region in 1911.

Figure 8 The proportion of total Aloe cultivation and of total agricultural land-use that was situated on each of the main geological formations, Aruba Lava Formation, Batholith Formation and Limestone Terraces, according to Busonjé (1960).

A similar association was observed in the other regions with erosion and sediment streambeds where dry-rivers had cut through the Limestone terraces (Figure 7). Alluvial sediments contain a high percentage of the hinterland rock substrate, in this case from a Quartz-Diorite/Tonalite hinterland (Sambeek, Eggenkamp, & Vissers, 2000).

Not indicated in Table 1, but it is interesting to note that 41.1% of all the area with the alluvial mud and sands that cut through the Limestone Terraces, were covered with cacti and stone fenced terrains (indicative for agricultural exploitation) against only 10.2% of the areas was covered with the Aloe fields (Figure 7).

Housing in 1911 and 2010

Housing at the beginning of the 20th century was scattered and spread all across the agricultural countryside, with the exception of Oranjestad and to some degree also Savaneta. There was a dominance of agricultural development other than Aloe cultivation in the central regions where farmers typically live next to their land.

We refer to the information from the Werbata-Jonckheer map that we digitized and translated into GIS layers and that we present in figure 9. Houses were typically absent near the northeast coast and in the hills of todays' National Park Arikok. Obviously, agricultural development was cumbersome in these areas. Inhabitation was absent as well in the lower-lying areas along the west coast where there were still large rainwater plains and along the northeast coast where salt spray was intense.

The vast Aloe fields were situated in the southwest on the Limestone Terraces, at a short distance from the coast, up to 2-3 km inland. Typically, the large Aloe fields were thinly inhabited. Exceptions exist on the alluvial soils where the dry-rivers cut the Limestone and in the south, along the stretch between Savaneta and Brasil up to San Nicolas. As suggested in a previous paper (Derix, 2016c), these areas may have different, more fertile, alluvial soils.

At the time, in 1911, houses were made from twigs and clay and from stone. Interestingly, most houses in the center of Oranjestad were (still) made from wood. Oranjestad also had the largest concentration of stone houses. Similar concentrations of stone houses can be observed in Savaneta, at the Balashi Gold factory and at the Phosphor-limestone mine in Culebra near Seroe Colorado (Figure 9). Some of these houses were built from bricks that had been imported from Amsterdam, whereas the houses that were built more inland commonly were built from locally available rocks and stones (Bakker & Klooster, 2007).

In the map of figure 9 we show the location of each of the individual constructions. The colored dots represent the types of construction material that were most common in 1911, i.e. stone-built, from clay, twigs and mud, or from wood. Quite a large concentration of man-made water wells were situated at some distance from the west coast, many of which were *wind-milled.* It is evident that all over the island there have been huge changes in the spread of housing over the last century, between 1911 and 2010 (compare figure 9 with figure 10). For the sake of comparison, we superimposed on the map in figure 9 the location of main economic activity in 2010.

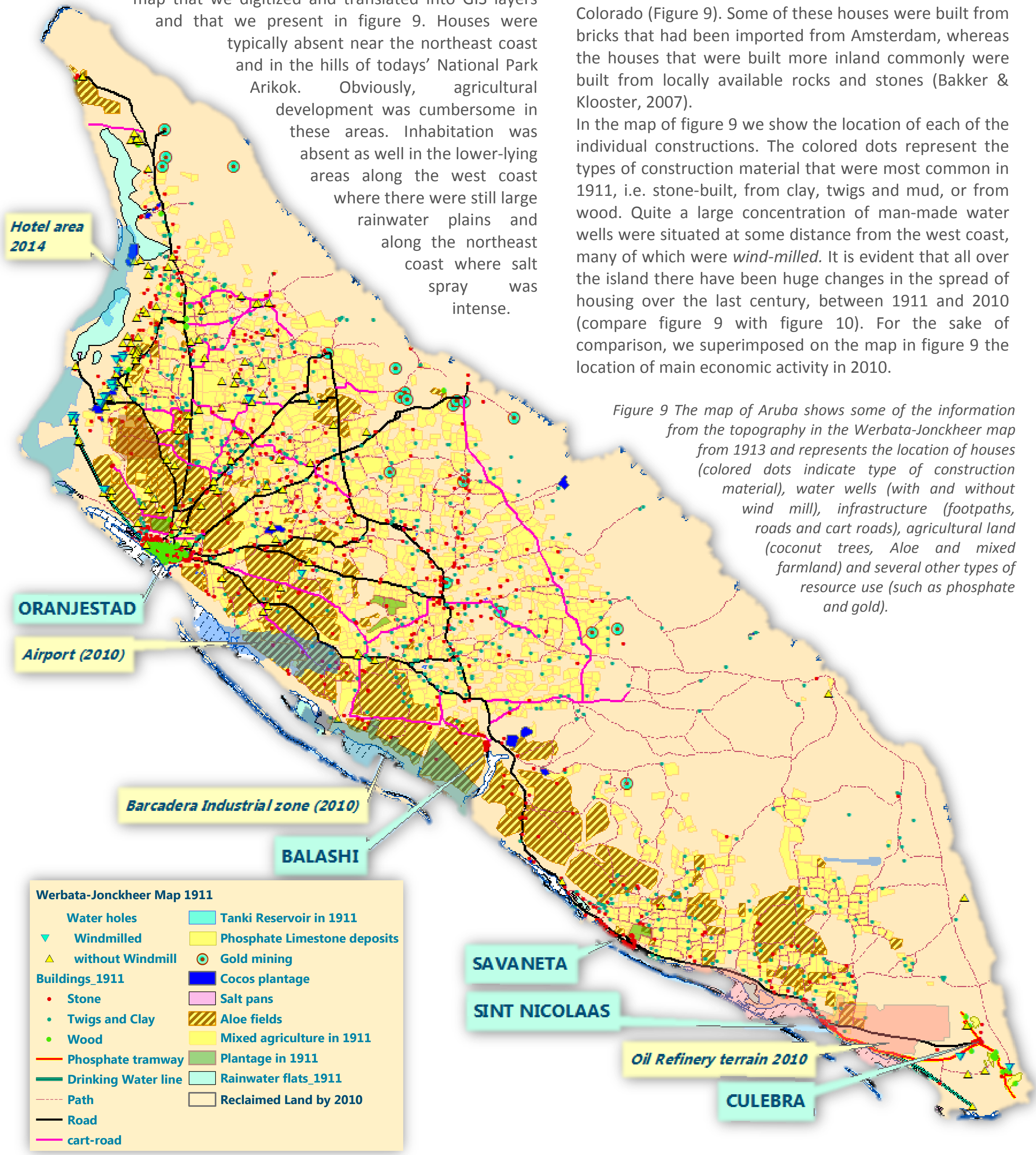


Figure 9 The map of Aruba shows some of the information from the topography in the Werbata-Jonckheer map from 1913 and represents the location of houses (colored dots indicate type of construction material), water wells (with and without wind mill), infrastructure (footpaths, roads and cart roads), agricultural land (coconut trees, Aloe and mixed farmland) and several other types of resource use (such as phosphate and gold).

Today, the wooden houses in Oranjestad have long been replaced by modern commercial centers. In San Nicolas, most of the wooden houses have been gone as well. The use of GIS enables to review the extent of construction from different time periods, superimposed on top of each other. Figure 10 reveals that some of the houses disappeared behind the walls of the oil refinery that were built some years after the start of the refinery, in 1929. This includes part of the historic city center of San Nicolas that was dismantled too.

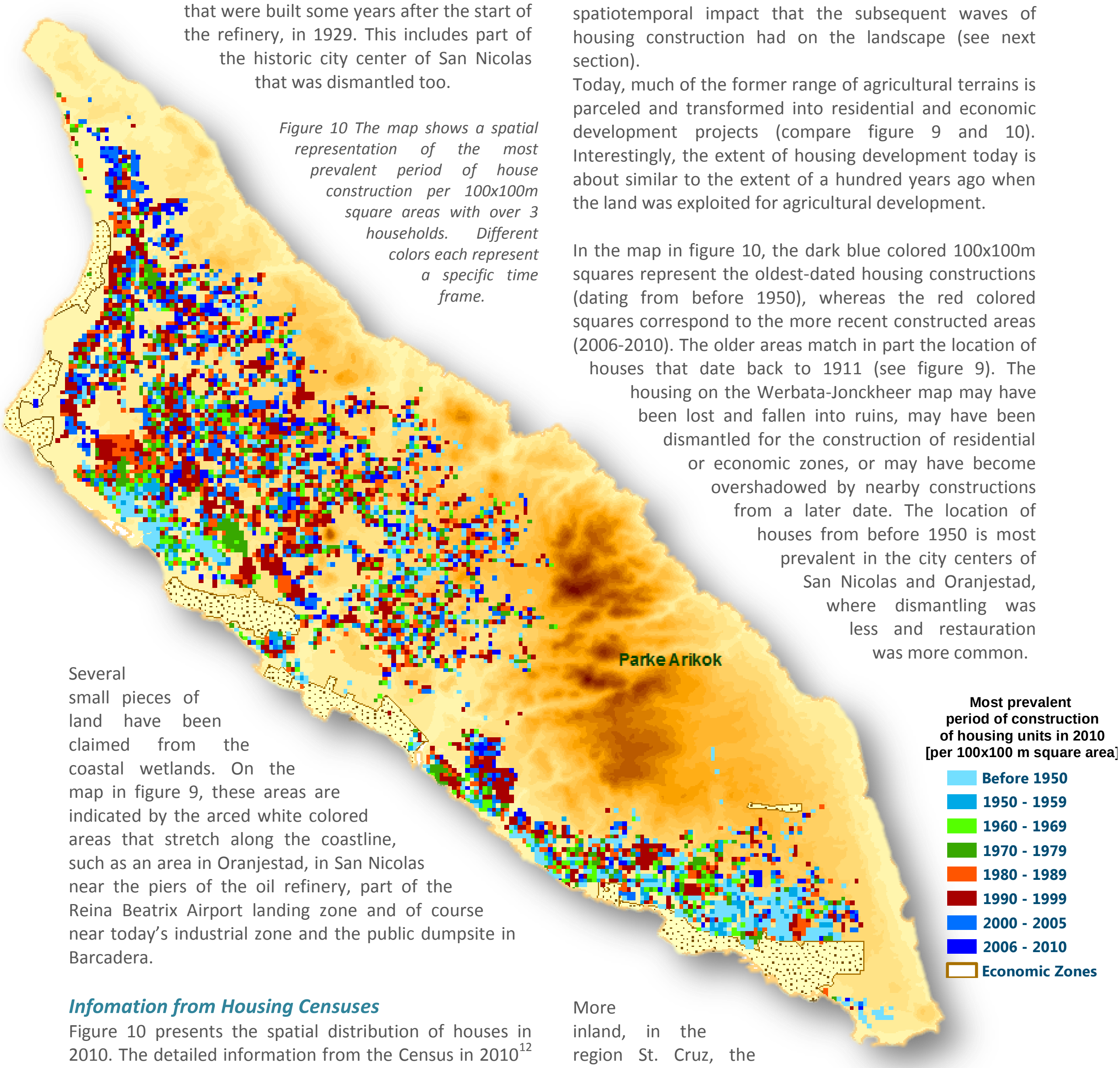


Figure 10 The map shows a spatial representation of the most prevalent period of house construction per 100x100m square areas with over 3 households. Different colors each represent a specific time frame.

Several small pieces of land have been claimed from the coastal wetlands. On the map in figure 9, these areas are indicated by the arced white colored areas that stretch along the coastline, such as an area in Oranjestad, in San Nicolas near the piers of the oil refinery, part of the Reina Beatrix Airport landing zone and of course near today's industrial zone and the public dumpsite in Barcadera.

Infomation from Housing Censuses

Figure 10 presents the spatial distribution of houses in 2010. The detailed information from the Census in 2010[12] (CBS Aruba, 2010) made it possible not only to distinguish the time of construction categorized in subsequent decades, but also to present this information at a spatial resolution of 100x100 meter square areas. The colored squared areas in figure 10 vary from blue, over to yellow, and red, and reveal the differences in 'most prevalent period of construction'[13] of the houses that fall within each of the 100x100m inhabited areas. Such fine level of spatial resolution is more informative than would be possible based on a representation by GAC zones (GAC, 2012). This is useful to better understand the actual spatiotemporal impact that the subsequent waves of housing construction had on the landscape (see next section).

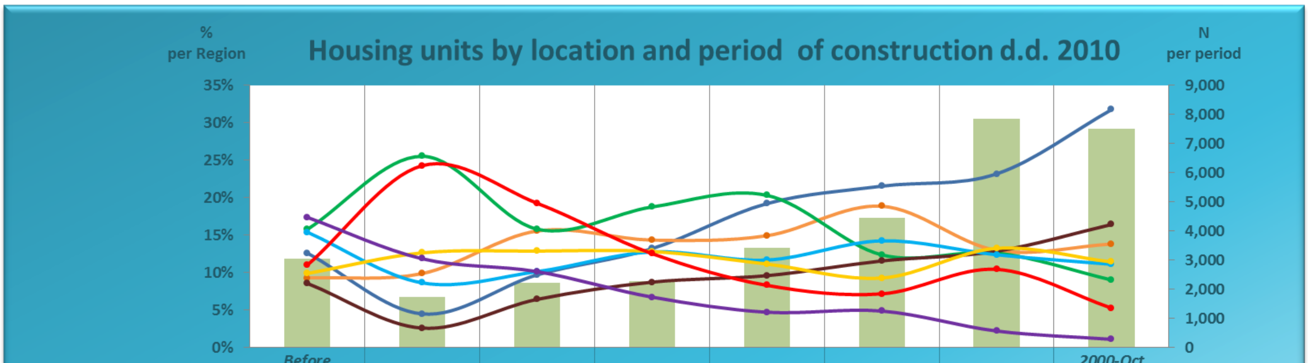
Today, much of the former range of agricultural terrains is parceled and transformed into residential and economic development projects (compare figure 9 and 10). Interestingly, the extent of housing development today is about similar to the extent of a hundred years ago when the land was exploited for agricultural development.

In the map in figure 10, the dark blue colored 100x100m squares represent the oldest-dated housing constructions (dating from before 1950), whereas the red colored squares correspond to the more recent constructed areas (2006-2010). The older areas match in part the location of houses that date back to 1911 (see figure 9). The housing on the Werbata-Jonckheer map may have been lost and fallen into ruins, may have been dismantled for the construction of residential or economic zones, or may have become overshadowed by nearby constructions from a later date. The location of houses from before 1950 is most prevalent in the city centers of San Nicolas and Oranjestad, where dismantling was less and restauration was more common.

More inland, in the region St. Cruz, the ribbon-like occurrence of houses from before 1950 is relatively common and still visible.

[12] During the Census in 2010, 7% of respondents did not provide information about the age of construction of the housing unit. The lowest percentage of 'not reported' was present in the larger region of Savaneta (3%) and the highest in the region of Oranjestad (10%). In Oranjestad many housing units are rented and quite old. Thus, inhabitants may have been unfamiliar with the precise date of origin of their living quarter.

[13] Houses that were constructed before 1950 are obviously over-represented since this category spans more than a single decade. On the other hand, the older the houses the more likely they have turned into a ruin or were demolished, even though nowadays there is a trend to restore and expand old houses. Likewise, an over-representation is present for the recent decade as this period includes an additional nine months, from January 2000 until the day of the Census, September 29, 2010.



	Before 1940	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-Oct 2010
All housing units (N)	3042	1736	2,218	2,277	3,435	4,450	7,840	7,520
Noord/Tanki Leendert	13%	5%	10%	13%	19%	22%	23%	32%
Oranjestad West	9%	10%	16%	14%	15%	19%	13%	14%
Oranjestad East	16%	26%	16%	19%	20%	12%	13%	9%
Paradera	9%	3%	6%	9%	10%	12%	13%	16%
Santa Cruz	15%	9%	10%	13%	12%	14%	12%	11%
Savaneta	10%	13%	13%	13%	11%	9%	13%	11%
San Nicolas North	11%	24%	19%	13%	8%	7%	10%	5%
San Nicolas South	17%	12%	10%	7%	5%	5%	2%	1%

Figure 11 Distribution of Aruban housing units per region and period of construction.
Note: Collective living quarters have been excluded from the analysis.
Source: Census 1991 and Census 2010, CBS Aruba

Not easily visible in the representation in figure 10 is the shift over subsequent periods of time in the location of economic and residential hotspots from San Nicolas northwards to Oranjestad and to the hotel area in Noord. We will discuss this transition next and refer to the representations in figure 11 and 12.

Quite revealing is the interplay of up and down going trends in house constructions per region[14]. The underlying information in figure 11 is from consecutive censuses in 1991 and 2010 and is based on the date of construction of the housing at the time of the Census. Old houses will certainly have been lost over time, possibly blurring the picture shown above. However, we may assume that the number of possibly lost houses will have remained low as housing stayed in high demand and there is a trend to renovate old cunucu houses and even ruins, as opposed to tearing these houses down.

The pattern in figure 11 is best described as a *wave of construction* across the island, based on a shift in local or regional interest in economic development or at least a shift in the interest for the new housing opportunities that each of these regions characterized during subsequent time spans.

Figure 11 shows that across all regions in Aruba, a near equal percentage of houses exist that date back to the period from before 1940 (range between 9-17%).

[14] For each of the regions separately we presented the frequency of new construction across the subsequent time frames as a line to ease readability and emphasize the shift in region-specific interest for new construction.

Of the houses that originate from the period 1940-1949[15] (during and after WWII), a disproportional large part, respectively 26% and 24% are located in the region '*Oranjestad East*' and '*San Nicolas North*'. These neighborhoods are the earliest indication of a wave of construction that first started to house the workers in the oil refinery at the time of WWII, which shifted northwards to house the workers in the tourism industry and the facilitation industry.

From all houses today, proportionally, the majority from the time 'before 1940', are still situated in *San Nicolas South* (17%) and in *Oranjestad East* (16%). From the houses that are built more recently, between 2000 and 2010, the majority are situated in the larger region *Noord/Tanki Leendert* (32%).

At the finer scale, this shift is detectable in the more complex figure 10 as well, when we focus on the dark blue and red colored 100x110m square areas only.

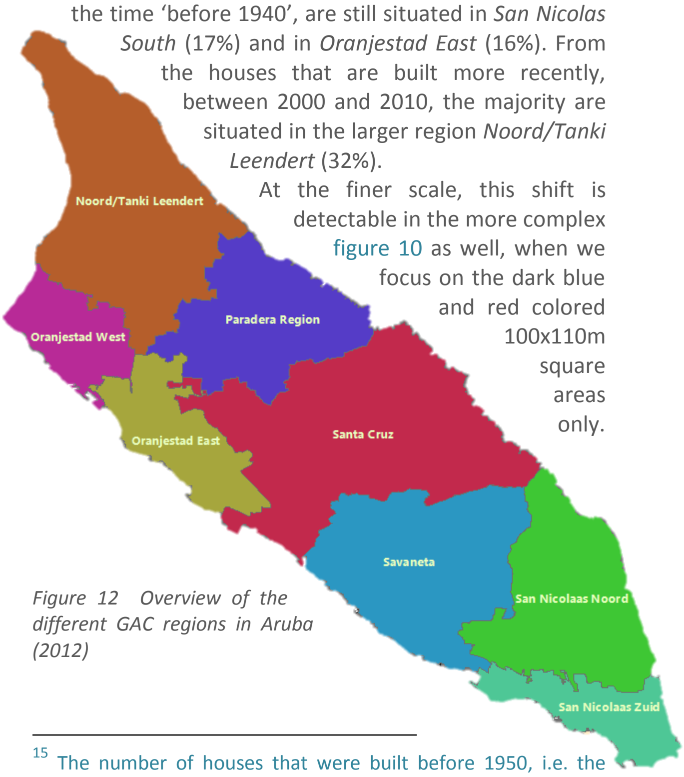


Figure 12 Overview of the different GAC regions in Aruba (2012)

[15] The number of houses that were built before 1950, i.e. the categories 'before 1940' and '1940-1949', were based on a combination of information from the Census in 1991 and 2010. The information from the Census in 1991 was only available at the level of GAC zones and regions, thus limiting the spatial resolution of the information that we show in figure 11.

In the 40s, economic interests shifted away from *San Nicolas South* towards predominantly *San Nicolas North* and *Oranjestad East*. The disproportional interest for new construction, however, dropped after WWII. Not only in *San Nicolas South,* where new construction already dropped from the '40s onwards, but more strongly so in *San Nicolas North* and in *Oranjestad East* that lost both their prominence during the '50s (follow respectively the purple, green and red lines in figure 11).

Figure 11 reveals that, proportionally, during the 60s and 70s new house construction was highest in the region *Oranjestad East* with respectively 19% and 20%. After the 50s house construction also increased in *Oranjestad West* (from a proportional 16% in the 50s compared to other regions up to 19% in the 80s, which was when *Oranjestad West* became the most desired location for new construction. Aside from this peak during the 80s, throughout the subsequent decennia the activity in house construction in the *Oranjestad West,* however, remained proportional at a quite steady level similar to the situation in the regions *Savaneta* and *Santa Cruz*.

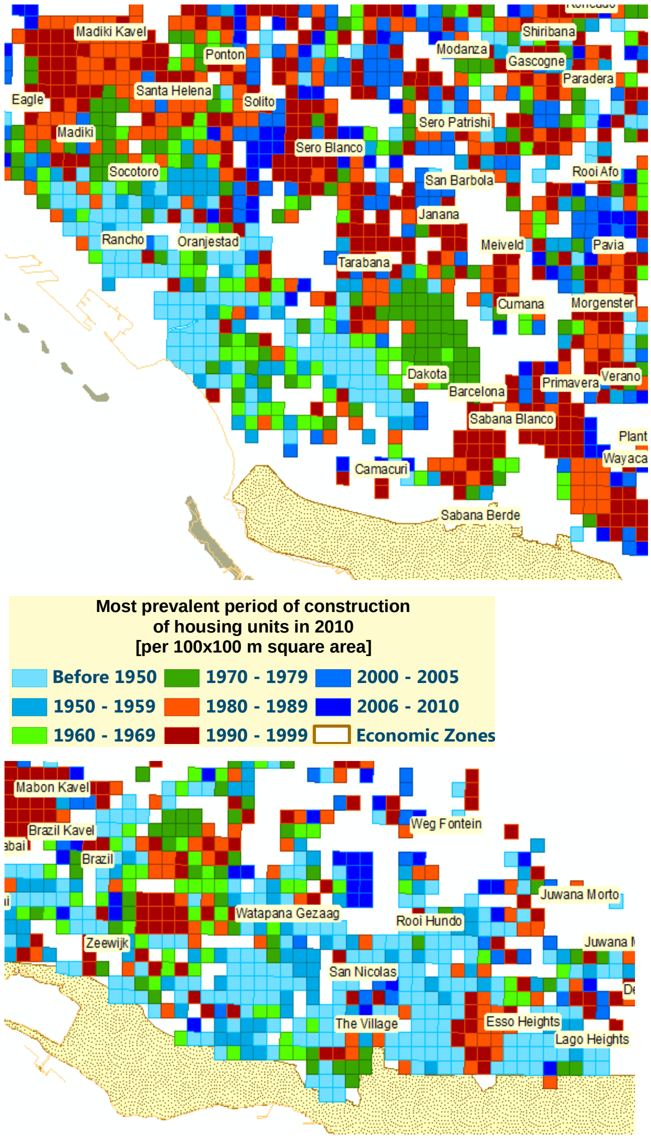
The pattern of house construction in *Noord/Tanki Leendert* and *Paradera* is different*.* While during the 40s the regions *Noord/Tanki Leendert and Paradera* received the least interest for growth in new construction, over time, the relative attractiveness for new residential housing steadily increased to become the regions where proportionally most new construction took place.

Summarizing, the regions *San Nicolas South, Oranjestad East* and *San Nicolas North* followed each other in prominence for new housing construction during the periods 'before 1940, the 40s and the 50s, whereas thereafter, during the 60s and the 70s this role remained for *Oranjestad East* consecutively, and from then onwards (80s, 90s and up to 2010) the region *Noord/Tanki Leendert* appeared pre-eminently most attractive.

There is another aspect of the island wide spread of housing construction that deserves mentioning. In the surroundings of Oranjestad (Figure 13a) and San Nicolas (Figure 13b) we recognize larger areas with predominantly similarly aged houses (Madiki, Rancho and Dakota and The Village and Esso Heights). These areas correspond to neighborhoods and former governmental housing projects that were constructed in a relatively short period of time to provide affordable housing for the workers[16] in the hotel and the oil industry, respectively.
Also, we can observe small neighborhoods with similar aged houses. These correspond to known small housing projects by foreign investors or by local land owners who, under own proprietary rule, parceled their land to sell the individual plots separately. Over the last decade, similar aged housing projects were built, but now they are found most frequently in the regions *Noord/Tanki Leendert* and *Paradera*.

[16] One of the two oil refineries at the time, the Arend Oil refinery (1928-1953), situates just north of Oranjestad, at the most western tip of the island. The other oil refinery situates in San Nicolas, in the South, and changed between its opening in 1928 and its last closure in 2012 several times from ownership.

Figure 13a (top) and Figure 13b (below) Distribution of Aruban housing units at the time of the Census in 2010 per most prevalent period of construction in Oranjestad (figure above) and San Nicolas (figure below).



In general, aside from the smaller and larger (non-) governmental development projects, there is considerable spatial spread in the time of new construction all across the island (see also figure 10).

As mentioned before, tourism and the accompanying facilitation industry are still booming and attract a range of recreation- and food-establishments at the strip near the high-rise hotels. These not only attract tourists, but local inhabitants as well. In a relatively short time span the area of Noord became the booming center of economic and recreational activities. Noord is currently considered to be the point of attraction for foreign investment projects. In contrast to local private housing projects, which are situated more inland, the larger projects in Noord have a focus on well-to-do foreigners. Many of the predominantly low-salary local workers in the tourism sector, however, live in Oranjestad or even come as far as from San Nicolas and cannot afford the high prices for new housing in the nearby region '*Noord'*.

Consequently, they commute on a daily basis over the relatively large distance between San Nicolas and the Hotel strip in 'Noord'. Figure 13 presents per 200x200m inhabited area, the most prevalent distances that employees cover to their work on a regular basis (Derix, Traffic between school, work and home in Aruba in 2010, 2013b). We will discuss the changes in infrastructure in more detail, next.

Impact from the shift in housing on the landscape

It is likely, that now, as residential construction has spread across most of the island, San Nicolas and surrounding areas may become once again attractive for housing expansion. After the closure of the oil refinery in 2012, the region lagged behind in economic progress, but there is still much inhabitable space available and plans exist to revitalize the economy in this part of Aruba with a restart of the oil refinery. If this materializes, it is likely that this will have consequences for the local landscape and natural habitats. A project to ease current traffic flow (Aruba, 2013) between San Nicolas and Oranjestad is already in development.

Consequently, in just over half a century, little by little, the wildered land or 'Mondi' disappeared in most regions as it turned into new development projects. Accordingly, the face of the former (wildered) agricultural landscape or cunucu transformed into its current suburban state.

As an illustration of the pressures on the natural space, we give a photo (below) that shows the eagerness of two local birds (Burrowing Owl) to find a suitable nesting site in the drastically changing landscape.

Photo: The arrows show two Burrowing owls () next to their new burrow in a temporary heap of shoveled earth in an area where the land was cleared for new housing development. The animals appear to be quite adaptable in finding a site as their old habitat withdraws in fast pace, but it is unlikely that they will be succesful as this heap of sand is only temporary and antropogenic disturbances will continue. (Photo: Ruud Derix, 2003)

It is notable that construction continues even in areas that formerly were undesirable for building, for instance close to the northeast coast under the pressures of the salt laden winds that easily corrode building materials, or, in the more central regions in Aruba amidst the heaps of large dioritic boulder formations. Destruction and removal of some of these rock formations is of consequence (Barendsen, et al., 2008).

The stretches along the Northeast and Southeast coastline form a few of the yet relatively 'untouched' habitats that are still left in Aruba and that play a role to serve local recreation and tourism. The stretch along the Northeast coastline is conveniently named already the future *'Salt Spray Park'* (DIP, 2009).

There is still some network of small wildered patches in the island interior, within inhabited areas, that are thought to play an important role as habitat corridors in preserving biodiversity. The small patchy network of interconnected habitats, however, is swallowed more and more by new developments. Aruba is in many cases the owner of the spots that together constitute a '*green corridor network'* for local plant and animal species. Action to protect and preserve the natural green corridor would be in concordance with the Spatial Development Plan (ROP, 2009) that was first postulated in 2009, but is under consideration today.

Infrastructure in 2010 and in 1911

The distribution of distances[17] from home to work, measured in 2010, reveals a stressing pattern with consequences for the intensity of road use, traffic congestion and fuel consumption. Figure 14 summarizes the results that have been explained in detail in a previous paper (Derix, 2013b). The study shows that there is a local concentration of employees in several areas in the south that have to travel the longest routes to work (the daily distance to work for many that live in San Nicolas is as far as 23 km; a stretch that corresponds with a distance to the Hotel area in the north). In contrast, a majority of those who live in or near the center in Oranjestad and in San Nicolas cover the shortest distances to work (i.e. a distance that suggests that they live close to work). Those who live in the region of Pos Chiquito on average cover an intermediate distance of about 11 km to work (i.e. their destination of work may be in either direction, Oranjestad or San Nicolas). Also, those that live in the more rural areas, east of St. Cruz or far to the north, travel intermediate distances.

A layout for traffic congestion

Aruba is about 30 km in length and on average about 8 km in width. In this area of approximately 180 km^{2,} close to *1,000 km* length of roads exists (Table 2).

At present, despite these many roads, the infrastructure turns out to be inadequate to cope with the daily traffic. Traffic, namely, suffers severe congestion in many locations, but most severely during rush hours in Oranjestad and in its surroundings. Oranjestad harbors primary schools and higher education centers (Derix, 2013b). As a result, Oranjestad attracts traffic from in- and outside the region. Furthermore, most parents bring their children to school by car, since the car is the prime mode of transportation to work as well as to school (Derix, 2013b). The percentage of parents that bring their children (across all ages) to school by car is noteworthy as many of the prime scholars actually live within only a short distance from the primary school (less than to 3 km). The result is that many parents get in and out of the city twice daily only to take their child(ren) to (often different) school(s) in order to pursue their way to work.

[17] The distance is based on the measure of Euclidean distance, i.e. as a straight line between home and work. No information was available on the actual route that is taken.

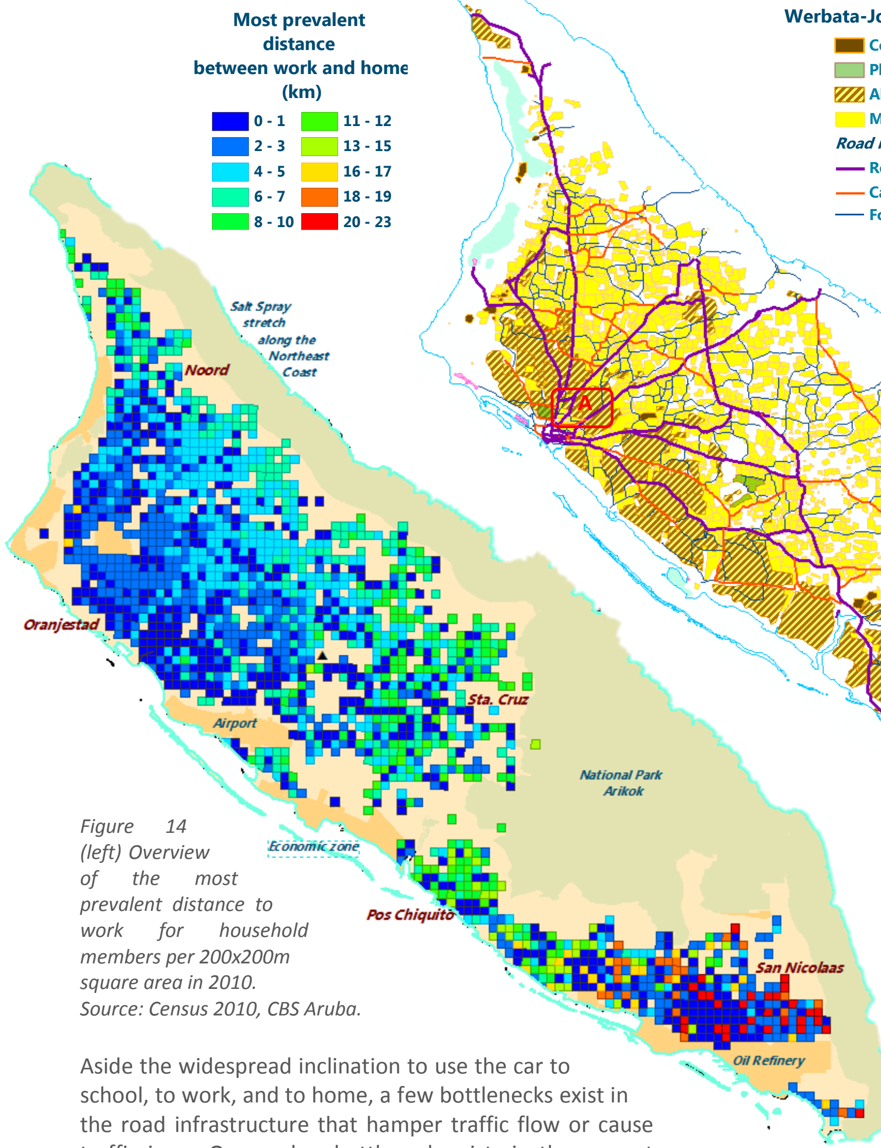


Figure 14 (left) Overview of the most prevalent distance to work for household members per 200x200m square area in 2010. Source: Census 2010, CBS Aruba.

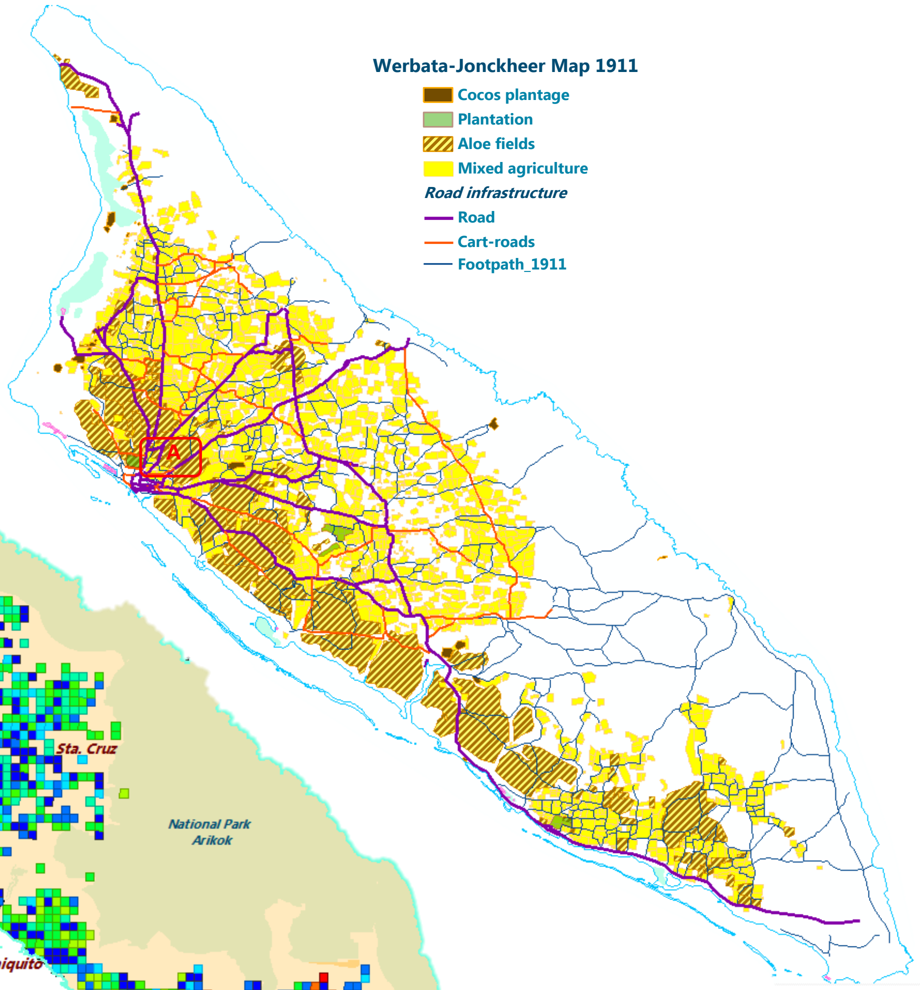


Figure 15 (right) Overview of the road infrastructure in 1911. The square (A) depicts an area that is explained in figure 16 and referred to in the text. Source: Werbata-Jonckheer map (1913).

Aside the widespread inclination to use the car to school, to work, and to home, a few bottlenecks exist in the road infrastructure that hamper traffic flow or cause traffic jams. One such a bottleneck exists in the area at '*Frenchman's Pass*'/ '*Balashi*' and another is at the '*De La Salle Straat*' and at the '*L.G. Smith Boulevard*' in 'Oranjestad'. In these areas only few roads serve the transit of daily traffic flow between the areas north and south.

This has been recognized a long time ago already, but large infrastructure projects are hampered by a complexity of historic land ownerships and juridical conflicts about the expropriation of terrains. For instance, to ease the traffic flow in and around Oranjestad an additional third ring and an extension of the inner ring is portrayed that leads traffic around the city (Figure 16).

To understand what influences from the past may have added to today's traffic problems, we choose a historical perspective and compared the layout of the road infrastructure today with the situation in the past

The layout of the road infrastructures in Aruba dates back at least a hundred years ago, when the landscape in Aruba was dominated by agriculture and the local exploitation of phosphate and gold encouraged the development of better roads. From about that time, a hundred years ago, a relatively precise and schematic topographic map exists, the so-called Werbata-Jonckheer map (Krogt, 2006).

The map dates from 1913, but provides us with very relevant information about the extent of land use and road infrastructure that was collected during the period *1909-1911*.

The information from the map shows that the outline of the main road infrastructure a hundred years ago corresponds well to the outline of the main roads today (Figures 9, 15 and 16). Over the years, the land alongside the main road connections turned more and more into residential neighborhoods, but differences in early agricultural land use had a differentiating effect on the opportunities for development.

In 1911, a fine network of unpaved cart roads and footpaths connected effectively in all directions. Oranjestad was much smaller than today, but it was already the heart of activity and trade, and the paved road infrastructure radiated from its city center to the hinterland (figure 15 and 16). At the time, in 1911, vast Aloe fields surrounded Oranjestad and the few roads that ran through these Aloe fields almost had no interconnections. In early 20th century there was probably no need either for roads to run parallel to Oranjestad.

Roads - DOW layer 2013	Type name	Asfalt	Beton	Klinkers	Olie	Zand	Material Unknown	
IRF category		*Paved*	*Paved*	*Paved*	*Unpaved*	*Unpaved*	*Unknown*	
Highway, Main or National Roads	Autosnelweg	47,337	-	-	-	-	-	*47,337*
Highway, Main or National Roads	Autoweg	59,466	-	-	-	-	501	*59,967*
Highway, Main or National Roads	Hoofdweg c.q. hoofdroute	59,144	-	-	-	-	2,604	*61,749*
Other Roads - Urban - Rural	Wijkweg	32,198	-	-	-	2,309	6,201	*40,709*
Other Roads - Urban - Rural	Buurtstraat	48,744	-	1,097	1,137	19,285	12,239	*82,503*
Other Roads - Urban - Rural	Woonerf	80,142	1,508	3,712	8,171	101,288	22,139	*216,960*
Other Roads - Urban - Rural	Woonstraat	67,726	-	109	1,551	22,071	11,847	*103,304*
Other Roads - Urban - Rural	Type Unknown	96,867	668	8,355	4,749	200,524	74,395	*385,557*
	Length (m)	*491,625*	*2,176*	*13,274*	*15,607*	*345,477*	*129,927*	*998,086*

Table 2 Road Infrastructure in 2010. The table shows a summary of the length (in meters) of the road segments in Aruba in 2010 per type of pavement. The category 'unknown' sums the road segments that have not yet been appropriately addressed.
Source: DOW and CBS Aruba

At a distance from Oranjestad, however, many small cart-roads and footpath's can be observed and ran between the small agricultural terrains. This well-connected network of cart roads and footpath's spreads to every corner in the landscape (Figure 9, 15 and 16). Interestingly, also a fine maze of footpaths runs close to the center in San Nicolas. The map shows that the region of Savaneta up to San Nicolas, in contrast to the area close to Oranjestad Center, was dominated primarily by small agricultural terrains and with only few Aloe fields. A similar network of footpaths was neither present nor required obviously, so close to Oranjestad.

In this context, we like to recall the information in figure 8. A major part of the countryside (mainly quartz-diorite substrate) was exploited in relatively small agricultural terrains with a variety of land uses, whereas, along the west and southwest coastline (mainly Limestone substrate) large Aloe fields dominated the scene (with the exception of the area of Savaneta, Brasil and San Nicolas and along the dry-river beds, where the substrate was alluvial muds and sands). So, it is important to understand that the infrastructure at the beginning of last century served its purpose well in terms of the required mobility in relation to land use (small or large terrains and dispersed housing). There were probably only few cars on the island at the time and most transport was done with carts and/or donkeys.

In brief, on the map of early last century we observe a difference between the vast Aloe fields and the rest of the agricultural land in regard to infrastructure. Where Aloe fields dominate the land, houses were scattered and roads and footpaths were scarce and not present in all directions. In contrast, the small agricultural terrains were interwoven with a myriad of footpaths that ran between cacti and stone fences and rarely crossed the land itself.

Figure 16 highlights an area east of Oranjestad and is taken from the map in figure 15 (indicated by square A). We added relevant information about the road infrastructure in 2010, as well as type of land use in 1911.
Whereas the fine maze of interconnections directly surrounding the center of San Nicolas offered good opportunities to develop, over the years, into a well-organized road infrastructure, the road infrastructure in and near Oranjestad was lain out to serve traffic in and out of Oranjestad, but was not suitable for transit traffic. As most roads were radially oriented, the large terrains in the vicinity of Oranjestad blocked transit traffic. In time, footpaths and cart-roads turned into roads, but their absence in the vicinity of Oranjestad made a natural transition to the road infrastructure that would explain today's challenges.

In time, as the agricultural terrains and Aloe fields were parceled one by one and transformed into new neighborhoods, the access in and out of the residences frequently did not interconnect to the roads from neighboring terrains. The delicacy of private ownership of the terrains involved may be the cause why the road infrastructure has never been subjected to drastic changes afterwards. Even today, it is extremely difficult to expropriate landownership to enable the development of an apt road infrastructure that meets today's requirements.

The snapshot of the overlay of maps from 1911 and 2010 in figure 16 exemplifies some of the consequences from the agricultural situation in early century. The colored background of the roadmap represents the historic location of Aloe and small cacti or stone fenced terrains. The parceling of the large Aloe fields likely resulted in large residential areas, whereas smaller residential areas today are located where former small agriculture terrains existed. Between these terrains, small wildered plots still do exist. Today's primary road system (colored in white) corresponds well to the roads and cart-roads from 1911 (colored in red and respectively in dark blue). Even the footpaths from 1911 (colored in light blue) correspond well to some of the roads in 2010.
So, in general, a paved road in 1911 became a main road in 2010 and a cart-road became either a main road or a secondary road. Also a number of the footpaths from 1911 turned into secondary or residential roads in 2010.

In figure 16 we show a snapshot of an area northeast of Oranjestad between the outer ring of Paradera and the inner ring of De La Salle Straat. Of the three radially oriented main roads that ran from Oranjestad eastwards, we labeled all road intersections by colored dots (see the caption of figure 16 for further explanation about the difference in color).
The map shows that there are only few cross-intersections (blue dots) and thus ample opportunity to connect in parallel to the center of Oranjestad. Only in a few occasions cross-intersections exist, but most of the residential roads end as a T-junction to the main road network.

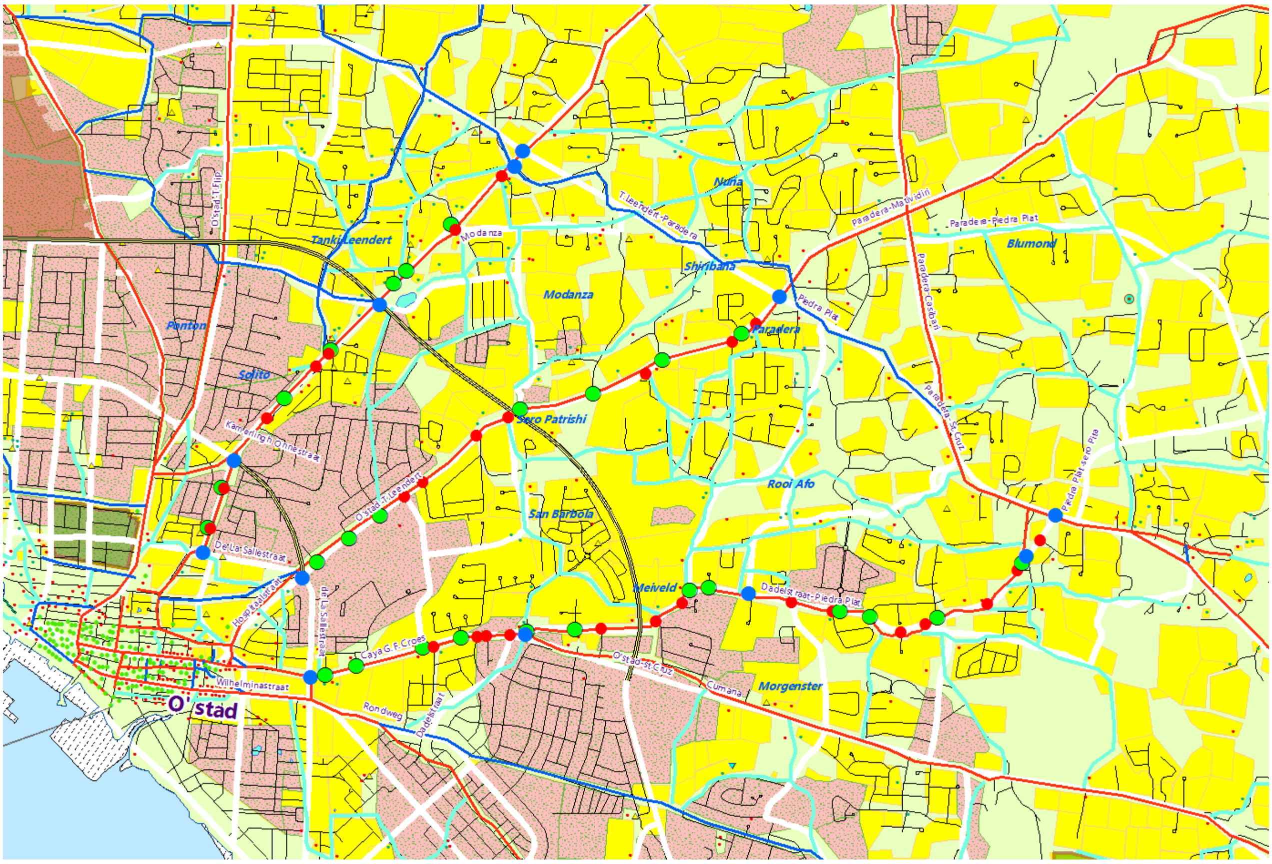


Figure 16 shows an overlay of the road infrastructures in the surroundings of Oranjestad in 2010 with information from 1911, based on the Werbata-Jonckheere map (Werbata, 1913). We focus on an area east from the center of Oranjestad. The pink and yellow colored backgrounds represent the extent of respectively Aloe fields and cacti- and stone fenced agricultural terrains in 1911. The lines (colored red, blue and light blue) represent respectively the paved roads, the unpaved cart-roads and the footpaths from 1911. The road infrastructure from 2010 is highlighted by white (main roads) or thin grey lines (residential roads).The projected inner ring extension and additional third ring is indicated by a brownish colored line segment, encircling Oranjestad.

For each of the three radially oriented main roads in 2010, as indicated in the picture above, we labeled the road junctions by colored dots. A red dot indicates an intersection with an access from the south to the main road. A green dot indicates an intersection with an access from the north and a blue dot indicates a cross- intersection. For further reading we refer to the text.

The few cross-intersections that do exist are likely used as shortcuts through residential areas, as there appears to be some level of inconvenience from local traffic in these neighborhoods (Derix, 2013b).

An improvement of the interconnectivity between south and north of Oranjestad is planned already (see figure 16), but is hampered by the required expropriation of terrains and housing. An extension of the inner ring is schematically projected as well as an additional third ring that will run parallel to Oranjestad, between the (outer) ring of Paradera and the (inner) ring of De La Salle Straat (Aruba, 2013) (DIP, 2009).

Final remarks

The review of land use in past history stresses the idea that the presence of large Aloe cultivation fields and small-scale cacti or stone fenced agricultural terrains had a differential impact on the location of current residential and road developments. In 1911, the infrastructure was adapted to the agricultural exploitation of the landscape and the orientation towards Oranjestad, whereas today, the infrastructure requires an orientation alongside Oranjestad as well. To some degree, we may conclude that the layout of traffic problems today already had been shaped by the size and orientation of the agricultural terrains in the past, and thus, by the composition of the soil substrate that defined the type of land exploitation in the first place.

No one in early last century, however, could have foreseen the development of the tourism industry at the northwest coast and the level of suburbanization today.

We like to emphasize that situations in the past have the potential to act as a matrix for subsequent developments. The example above, in which we suggest an influence from the type of agricultural subsistence on later road development and traffic issues even a century later, makes clear how important it is to have some historical notion and understanding of the interconnectedness between events in time.

We will also deliberate on the significance of a multisector approach in problem-solving. Information tools such as GIS technology that base on the spatial location of information have grown in importance.

Our findings that show a strong association between the location of Aloe cultivation on the Limestone Terraces and the location of small cacti and stone fenced agricultural terrains on the Aruba Batholith and fertile alluvial mud and sand deposits on the larger dry-river beddings in 1911, was analyzed with the use of GIS technology. Modern GIS technology provides the means to exchange, combine and analyze information from different fields, including geological, historical, economic and environmental data, and helps to better understand the challenges that we face.

To be able to have access to up-to-date information from a variety of fields and different expertise, we need to organize and maintain a library of compatible information, under guidance of a dedicated central authority, with its focus and the management and maintenance of such a GIS-based framework for collaboration and information sharing.

It is our belief that the multidisciplinary use of detailed local spatial information is essential to better understand and be able to tackle the environmental issues at the societal and economic interface that we face today in Aruba. This paper is part of a series on the Aruban landscape and focuses on information from history and land use in particular.

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Landscape series 5

Housing and accommodation in recent decades in Aruba

Tile painting by Dan Jensen From: *www.lago-colony.com*

The Aruban landscape has undergone many changes in history. This paper is part of the landscape series:

"Spatial Developments in the Aruban Landscape: A multidisciplinary GIS-based approach derived from geologic, historic, economic and housing information"

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Contents

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Aruba
2016

We like to thank our colleagues at the CBS for their comments on the manuscript.
Special thanks to Marlon Faarup, Director CBS, for the thorough review and remarks on the final manuscript.

This paper is part of a series on the Aruban landscape. To bring perspective to current environmental threats and developments we provide, in this paper, based on information from the Census in 2010 (CBS, 2010)*, a detailed view on the spatial pattern of distribution of a number of housing characteristics that link to environmental sustainability and the wellbeing and health of local living conditions.*

Housing and accommodation in the past

Until the end of the 18th century[1], personnel of the Dutch West India Company (WIC) housed in Noord[2], near the Indian community that resided in the surroundings of Alto Vista, at Fontein (near the only natural freshwater well) and near 'Paarden Baai'[3] (due to its accessibility as a harbor).

With the construction of Fort Zoutman at the 'Paarden Baai' in 1797-1798, housing at the bay became more attractive. The WIC commanders already had taken position near the bay, in Hato and in Ponton. The name 'Paarden Baai' is reminiscent of the shipment activities at that time, when horses (Dutch: 'Paarden') were transshipped between Venezuela and Jamaica. After the first king, Prince Willem I of the family '*Oranje',* came to rule the 'United Kingdom of the Netherlands', the name of the small township at *Paarden Baai* was changed into *Oranjestad* in 1824 (Alofs & Romondt, 1997). Oranjestad grew to become the capital and center of trade activity in Aruba.

Today, most public offices, financial and legislative institutions and trading companies have their businesses in or near Oranjestad. Thanks to its central geographical location and proximity to the gold melting facilities in nearby Balashi, the township of St. Cruz prospered as well, but lost some of its prominence when the gold industry came to an end. San Nicolas already served the shipments activities from the phosphor industry in nearby Seroe Colorado, but when the Lago Oil Refinery opened its doors in 1929, San Nicolas became a bustling city. New construction for housing and accommodation closely followed this spatial pattern of economic opportunities and prosperity in the different regions (Derix, 2016d).

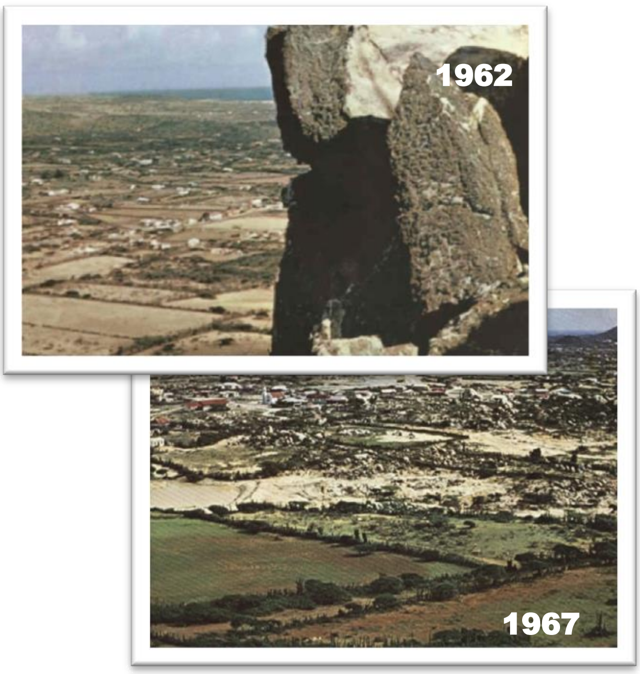
Built on the wind

Current housing units in Aruba may date as far back as to the beginning of last century and reflect the building styles of subsequent periods of external influences, economically as well as culturally. To get an idea of the different housing styles, the way of living, and the economic and political developments in Aruba over the last century we refer to the illustrative book by Bakker and Klooster (Bakker & Klooster, 2007) and the review by Alofs and Merkies (2006). The title of this section 'Built in the Wind' refers to the same title of the book by Bakker and Klooster, in reference to the typical way of construction of the former cunucu houses. We give a short impression.

At the turn of the 19th into the 20th century, at the time when the Werbata (Werbata, 1913) maps were made, houses were constructed from locally available materials. The Werbata map accounts three different types of houses. Walls were made from wood, from twined branches, plastered with mud and clay, or from blocks of granite and quartz diorite stone. The stone houses typically had thick outer walls and small rooms, but were cool and well ventilated. The tile painting by Dan Jensen (see the photograph on the front cover) is illustrative of the shape of the cunucu houses at the time. The bedrooms were commonly facing the windward side of the house. In a corner inside the house there was a water cistern that held fresh and cool rainwater. The kitchen was at the side of the house off the wind, to prevent the instant spread of fire from an accidental flare. The entrance was often to the west, also off the wind to prevent dust from getting inside. The oven was built against the kitchen wall and originally only accessible from the outside. Only after the outer walls were made from stone, it was safe enough to have the oven accessible from the inside.

With the growing population, the arable land surrounding Oranjestad was more and more developed for agriculture. Attempts to cultivate on the lower grounds near Santa Cruz proved to be successful and the initiative was soon followed by the exploitation of soils in the outer regions (Alofs, pers. comm.). Terrains were fenced by loose stone walls ('transhi') or built with columnar cacti tranches ('trankera') to keep the free roaming herbivores outside (or corralled). Stone walls were also used to prevent the land from erosion. Original mansions and row-houses were typically influenced by Dutch tradition, but with the arrival of the oil industry, American architecture was introduced. Interestingly, many houses in San Nicolas were built in the typical Caribbean style architecture in an effort to comfort immigrant Caribbean workers (Alofs & Merkies, 2006)

Photo series 1: An impression of the open agriculture landscape in 1962 (A.J. Casali, Lago calendar) and 1967 (Lago calendar). Both photographs were made from the top of the Hooiberg, and were oriented towards the Northeast. Source: www.lagocolony.com



[1] L. Alofs, pers. communication, 2016.

[2] The settlement Noord was established in 1774 (Alofs & Romondt, 1997)

[3] *Paarden Baai* translates in English as 'Horse Bay'

The photos below and on the previous page illustrate the open wide panoramas in the landscape in 1948, 1962, and in 1967. In 1948, already some of the fields were left abandoned, but the countryside was still dominated by Aloe fields and agriculture (Photo below). In the fifties, Voous (1955) and Stoffers (1956) described the landscape as generally very barren and dry and without much vegetation. Wild vegetation was merely along the dry-river beddings and in the region that roughly depicts Parke Arikok today. Agricultural terrains were largely abandoned and overgrown already (Stoffers, 1956).

The countryside in the sixties (see photos) was also still reminiscent of the open agricultural panoramas, dominated by the cacti, tree and scrub borders. The apparent bare landscape was without much vegetation, probably due to prolonged periods of relative drought. This and the decennia before were the times when many of the decision makers of today grew up. The landscape called '*Mondi'* was overgrown with cacti, herbs and shrubs but had the accounts of the beauty and hardship of the former cunucu landscape. With the new focus on economic prosperity and financial growth, there was little respect for nature. The situation was soon to change even more as the population numbers increased and the countryside was turned into housing projects.

We added to the image in figure 1 some color to stress the contrast between the extent of the dominant agricultural countryside in 1948, somewhat at a distance from Oranjestad, the large (former) terrains with Aloe cultivation in the immediate surroundings of Oranjestad, and the more densely inhabited center of Oranjestad.

It is interesting to analyze and reveal the patterns that accompany the strong increase in construction from last decennia (Derix, 2016d). Variation and changes in household characteristics, such as the size of the living space, type of building material, and the presence of air conditioning units, link to ambitions of a more sustainable and environmentally friendly environment.

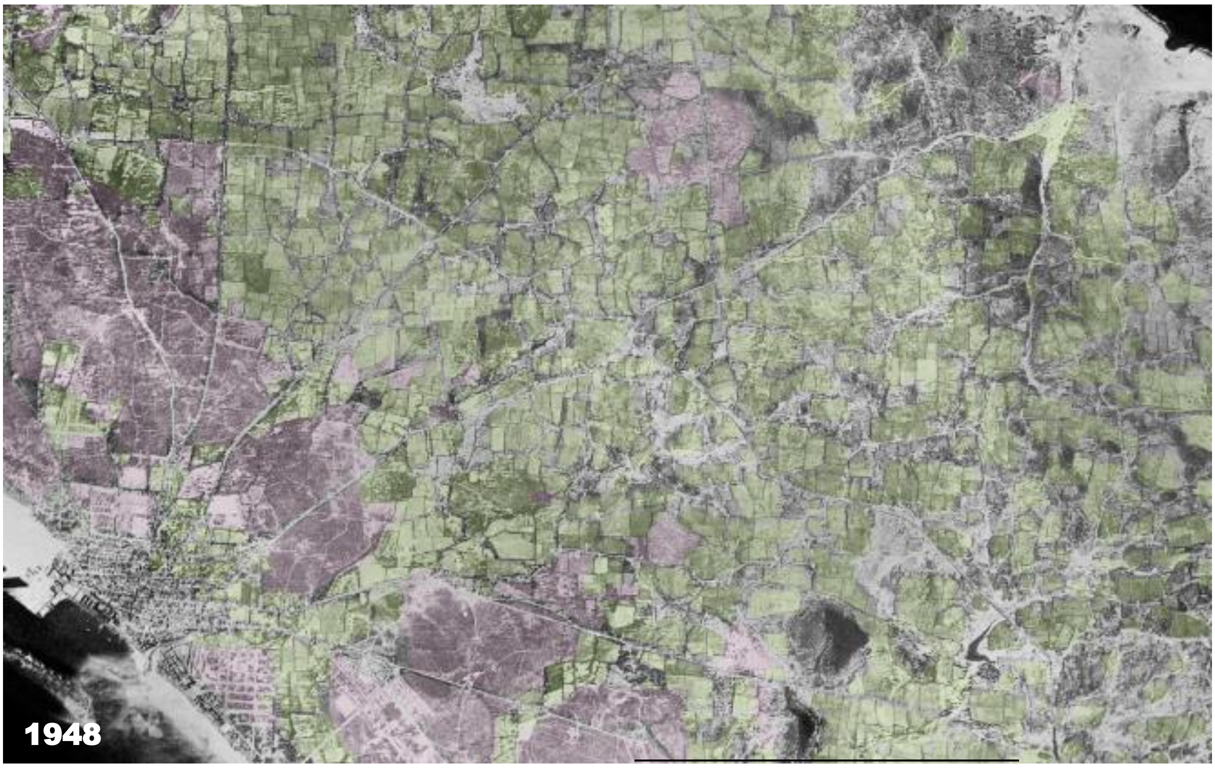
Housing characteristics

First, we describe the spatial variation in housing characteristics in Aruba at the time of the Census in 2010. Based on the information from the housing census we have analyzed the individual housing characteristics and the different building materials to the periods of construction. Our aim is to reveal trends in the way we use and shape our local environment.

The size of the built-up area, the use of different building materials, or the type of rooftop material may show an association with household budget, but may also depend on time specific common practices or local availability of materials. Some materials are more expensive than others. Also, some regions are more desirable than others (Derix, 2016d). Regional variation in housing characteristics may reflect differences in the privilege to build in certain areas and can have a different effect on the facet of the landscape.

The technique to measure and analyze the dependency among characteristics in a geographic space is called 'spatial autocorrelation statistics' and takes into account the co-variation of properties with each other and with space. Such spatial analysis includes a variety of techniques, and is still in development[4].

Figure 1 Aerial photo from 1948 (KLM Aerocarto map)
We colored the b/w photograph partly in purple and green to point out where in 1911 the terrains with Aloe cultivation and mixed agriculture, respectively are situated. The information is based on information from the Werbata map (Werbata, 1913).



[4] *www.spatialanalysisonline.com*

Square gridded areas with on average large household *plot sizes* (grid cells colored in red) show no concentration in specific regions, albeit that large *plots* appear to occur more likely at the border of uninhabited space (where there are no grid cells).

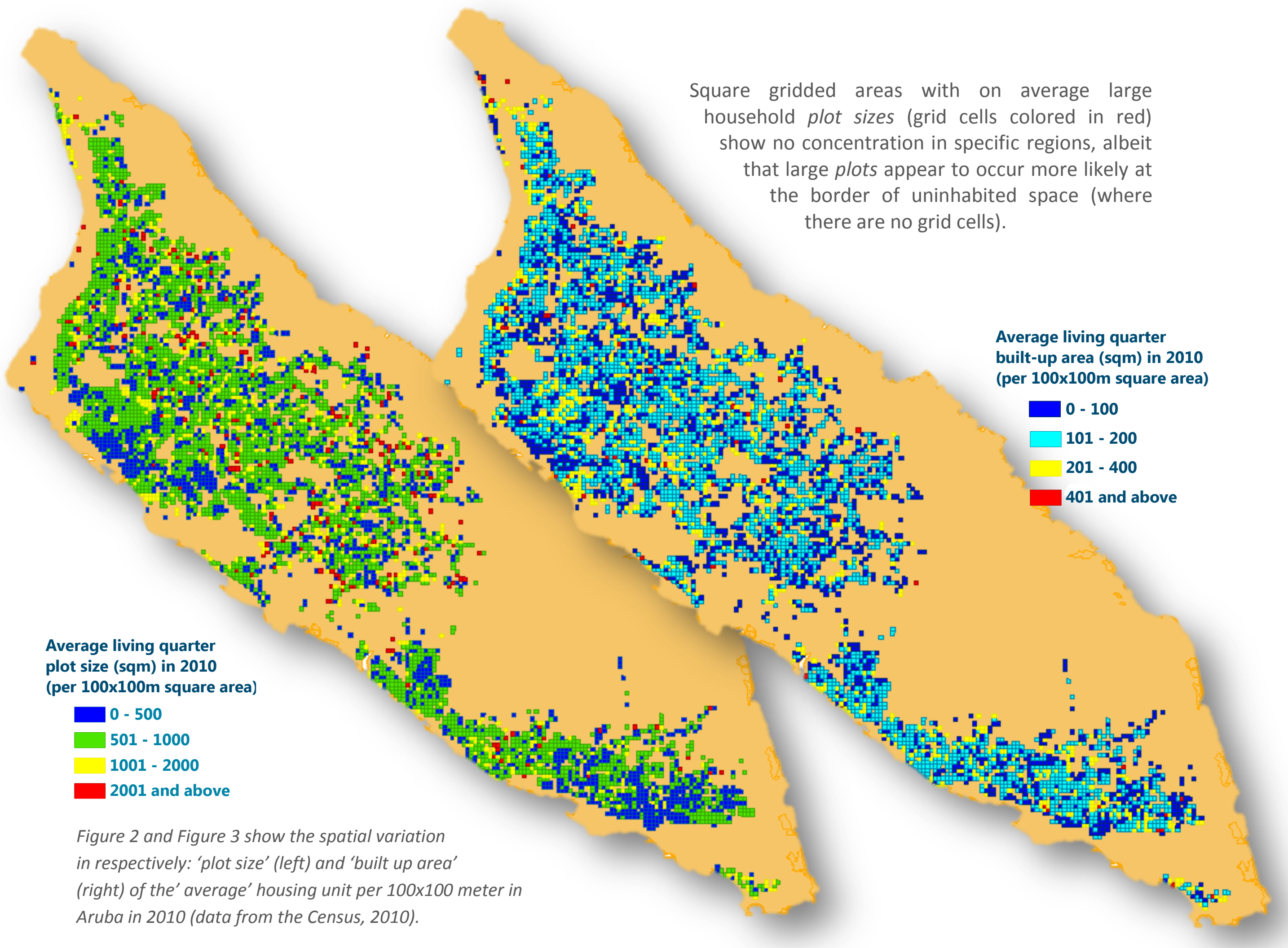


Figure 2 and Figure 3 show the spatial variation in respectively: 'plot size' (left) and 'built up area' (right) of the' average' housing unit per 100x100 meter in Aruba in 2010 (data from the Census, 2010).

A simpler regression analysis to analyze the spatial distribution of housing characteristics may prove inadequate as we have no means to control for the fact that, consequential to the typicality of spatial characteristics, "near features are more likely to be similar to each other than to distant features".

For the purpose of our study, we chose to simply describe the variables in a two- or three-dimensional space and refer to them as a tentative induction of underlying patterns. Therefore, we cannot be conclusive about the causal relation between the observed phenomena, yet our findings suffice to show trends and the corresponding spatial associations.

Smaller plots and living quarters

First, we analyzed the distribution of plot sizes and built up areas at a spatial resolution of 100x100 meter square areas (figure 2 and 3). We used the average as a parameter because our focus is on a comparison of the surface areas and less on the frequencies of occurrence.

Visually, we cannot discern any spatial pattern other than the expected local concentrations of similar sized small *building plots* and *built up areas* in the city center in Oranjestad and San Nicolas and in a number of areas that concern residential development projects.

Interestingly, in *plot size* as well as in *built-up area* an equal spread and variation exists across all the inhabited space.

Similarly, there is no specific pattern recognized in the spatial distribution of *large built-up spaces*, aside from some concentration in neighborhoods like *Malmok*, *Ponton*, Mon *Plaisir, Wayaca* and *Seroe Colorado*.

Figure 4 Relationship between period of construction of the living quarter, plot size, and built up area (Census 2010).
Note: The last decennium 2000-2010 is split into two categories 2000-2004 and 2005-september in 2010.

The graph in figure 4 shows a categorization of *plot size* and *built up space* in 2010 by 'period of construction'. The graph reveals that from the 1960's onwards there is little or no apparent change in *plot size* (the median value per grid cell is about 600 m^2 per housing unit). We do observe a peak during the 1980's as the median plot size over that time period is somewhat larger, about 650 m^2.

The median plot size of older housings built during the 1950's, is clearly smallest (500 m^2). We find many small plots in the direct surroundings of Oranjestad and San Nicolas (Figure 2) in areas with housing projects from the 50s (see also an earlier paper in this series (Derix, 2016d)). In regard to the size of the *built-up area*, a trend is noticeable towards smaller built-up areas from the 80s onwards. The smaller plot size concurs with the rapid growth of the population, the increase in costs of construction, and the increased demand for new housing (Derix, 2016d).

Less rooms and more floors

Based on information about the period of construction, and a number of housing characteristics, such as the amount and size of living spaces inside the house, the number of floors and the household income, we can show how we managed to attain a higher standard of living over the last fifty years.

The analyses (Figure 5) reveals a shift towards *fewer rooms* per housing unit from the fifties onwards. A '*room*' is defined to include *all bedrooms, the dining room and/or living room, the kitchen, and, when present, also the enclosed patio/veranda/porch.*

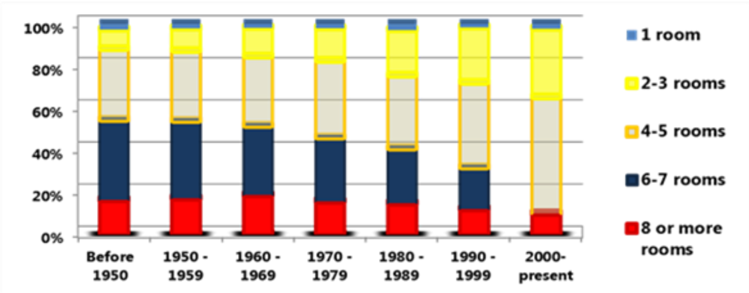


Figure 5 Percentagewise distribution of number of rooms per living quarter per period of construction (Census, 2010).

Thus, older housings generally have more rooms. In 38.6% of the housings that still exist from the fifties we observe 6-7 rooms and in 15.8% of cases there are even more than 8 rooms, whereas only about 9.4% of these housing units have 2-3 rooms. The number of rooms per housing unit decreased up to an average of 4 to 5 or even less in the most recently constructed housing units. New housing units built over the last decade have on average in 18.3% of cases 6-7 rooms, in 44.4% of cases 4-5 rooms, and in 26.2% of cases only 2-3 rooms.

Without further illustration, we like to note that at the spatial resolution of administrative (GAC) zones (N= 48) little or no geographical variation existed with regard to the *average number of household members* and *number of bedrooms per housing unit.* The ratio of *household members per bedroom* provides a good insight in the level of crowdedness in a given area. Across all zones, we observe in 26% of housing units more bedrooms than there are actually household members, in 54% of cases we count an average of 1-2 persons per bedroom, but in 16% we count 2-3 persons per available bedroom, and in 4% of cases there are even more than three (3) persons counted per bedroom. In only a few zones these numbers differ from the average, i.e. at the one end of the extreme, in *Seroe Colorado,* where we observe that the majority of housing units (58%) have more than one *bedroom* per household member available, and, at the other end of the extreme, is *Madiki* and *Rancho,* where we observe in 10% of housing units an average of more than three (3) household members per available bedroom.

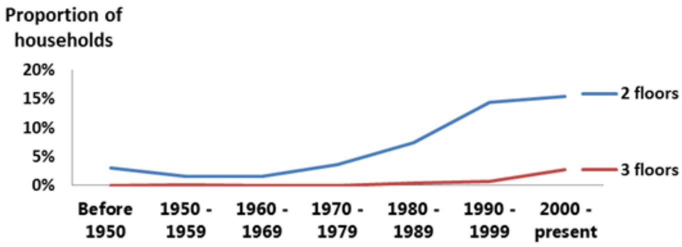


Figure 6 Proportion of housing units that have multiple floors per period of construction (Census 2010).
Note: In order to emphasize the temporal changes we represented subsequent period intervals as a line diagram.

Another striking trend is that more recently constructed housing units, in the last decades, have more often *multiple floors* with living quarters compared to houses that are built before (Figure 6). Housing units that were constructed after 2000, have in 15.4% of cases two (2) floors and in 2.7% of cases even three (3) floors. Houses built before 1950 have more than one single floor only in 3.0% of cases.

Income and the choice of housing materials

The next step in our analyses was to determine the relationship between building characteristics, such as the size of the plot and built-up area, the presence of fencing, the type of construction material, and the total household income[5].

Old cunucu houses had thick walls and are known for a mild climate inside. The thick walls not only had a high thermal mass, but were built with natural stone and cemented together by a mixture of mud and sands. These natural materials allowed evaporative cooling of the house interior. Cooling by ventilation was neither a problem since the old cunucu houses were generally well positioned in the wind.
The technique to construct thick outer walls is not in use anymore because of the elaborate work and costs that come with it. The use of cement blocks requires less maintenance and they are easy to handle, offer more flexibility for construction and are weatherproof, robust, and durable. The disadvantage is that to lower the costs of building, new-owners generally prefer single-stoned walls. The result is that with the heat buildup at the sunny side of the house façade the thermal capacity of the cement blocks is insufficient to prevent heat transfer inside. Therefore, to lower the heat buildup from the outer envelope of the house and improve the interior climate conditions, air-conditioning systems are installed nowadays.

[5] The total household income is defined in broad income classes and includes the earnings from all household members, based on the information that was provided by the household members during the household Census in 2010.

Shading from trees and other vegetation is considered an alternative to prevent the heat buildup from sun radiation on the outer walls and also increase the micro-climate conditions in the garden surroundings by evaporative cooling (Akbari, 2002). Vegetation too close to the house, however, is often undesired or impossible. Therefore one may consider reflective coatings or other insulation techniques, which exist for rooftops[6], to prevent heat absorption of the outer envelope of the house and protect against radiative heat emission inside.

Concerns about the costs, quality and energy efficiency of materials and techniques used in construction apply for the complete housing envelope, including the roofing material that is used. Roof tiles generally provide a somewhat better thermal performance and protection against the heat radiation inside, than shingles and metal sheets (Akbari, 2008). The commonly used technique, for instance when metal plates are used as rooftop material, is to construct a lowered ceiling. The large air-filled heat storage capacity above the ceiling protects against heat radiation directly inside the living space. We lack data about its occurrence, but it is safe to say that many of the houses in Aruba, that generally have only a single floor, do have a lowered ceiling, albeit that it is fashionable nowadays to have the lowered ceiling removed.

The analysis above (Figure 7) reveals a positive relationship between the *size of the plot* or *built-up surface area* and the *total household income.*
In lower household income situations (below Afl. 1,550 per month) we observe a flattening of the curve as the median built-up area remains at about the same level (ranges between 70-84 m^2). The results show that living space can be considered a scarce good and those who can afford it are privileged to attain more of it.
We chose to compare household characteristics with the total (categorized) household income and not to take into account the number of household members that will certainly have an effect on the height of the household income. To minimize the influence caused by the incidental presence of very large plots[7] or large size of the household, we used the median value instead of the average.

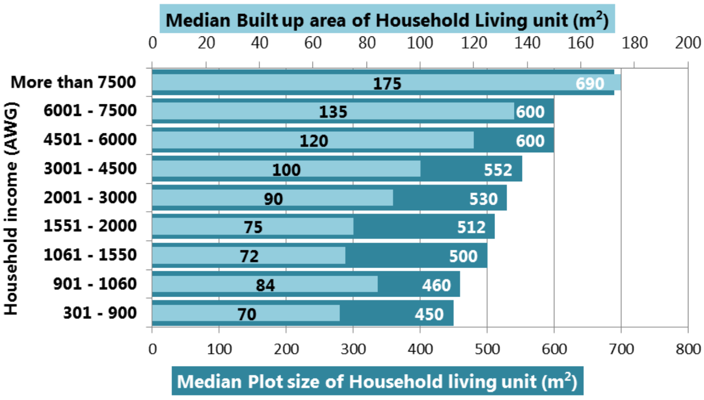


Figure 7 The graph presents the relationship between household income, plot size, and built-up area of the living quarter, based on the data from the Census in 2010.

Another housing unit characteristic that may relate to the privilege of a higher living standard is the level of fencing of the home compound. The 2010 Census data show that, overall, more than half of all households have fenced the land surrounding their living quarter completely. Figure 8 shows that the proportion of fencing does increase with higher total household income.

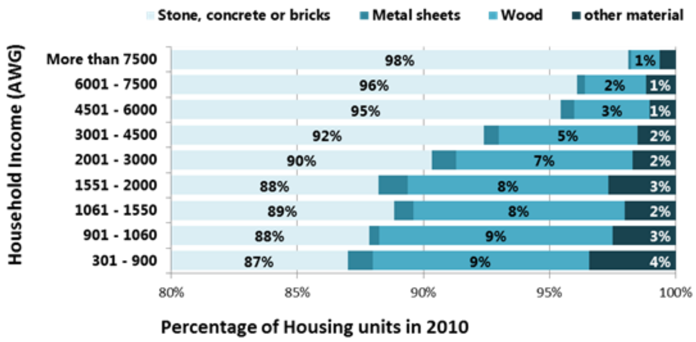


Figure 8 Relationship between total monthly household income and level of fencing around the living quarter.

In the household income classes below Afl 4,500 per month, the proportion of housing units that are completely fenced, partially fenced, or have no fence at all, remains about the same, irrespective of total household income.
In these (low and medium) income classes, in about 19%-21% of cases the terrain is partially fenced, while 22%-25% of housing units had no fence at all. The majority of housing units in this income range, however, (55%-58%) have their plot completely fenced. In higher income classes there is a trend towards complete fencing.

[6] When the sun's radiation hits the roof it strongly depends on the roof material properties and construction design of the roof envelop to determine how much heat will be transferred into the living spaces below. Important properties are solar reflectance (the fraction of the sun's radiation that is immediately reflected back into the sky), absorption (the fraction that is absorbed by the roof material), conductivity (the ability to transfer some of the absorbed heat away from the source) and the thermal emittance (the ability to radiate some of the absorbed heat). These properties, however, are no constants, but vary with varying climatic circumstances and aging. The essence of a cool roof (and walls) is to minimize solar heat buildup and heat radiation inside and to maximize reflectance. In addition, alternative approaches may involve additional insulation or a different design of the outer envelope that allows for ventilation (i.e. elevated batters) or evaporative cooling of the air flow/convection on top of the roof surface.

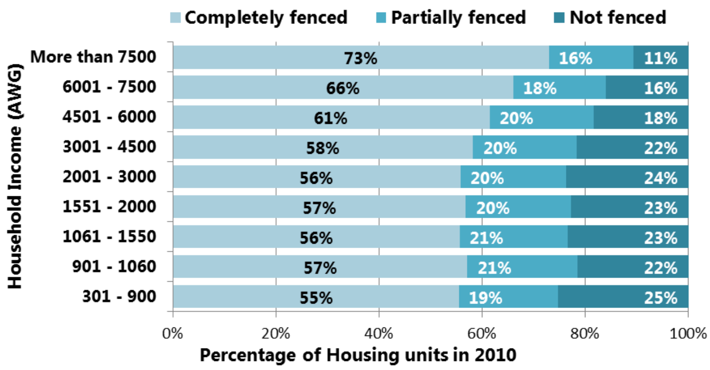
[7] Figure 3 and 4 have shown that there is considerable spatial variation in built-up area and plot size as well as a concentration of similar sized (parceled) plots predominantly in the centers of Oranjestad and of San Nicolaas and in the local housing development projects. Large plot sizes do still exist, however, and may be in family possession for a long time. To prevent that incidentally exceptionally large plots (or built-up areas) bias the outcome, we chose to present median built-up area and median plot size per category instead of the average.

In the income class ‘above Afl 7,500’, the trend is towards complete fencing, i.e. 73% of housing units have their plot fully fenced, 16% have partial fencing and only 11% have no fence at all.
The results show that fencing is less considered a luxury good and is present in over half of all households, irrespective of their income. The results also suggest that still, for those who may be able to afford it (observable in the household income classes above Afl. 4,500), there is a tendency to have their house completely fenced dependent on household income.
For the majority of living quarters in Aruba the prevalent material to construct the living quarter is by concrete-blocks (in Papiamento: *Blokki)* or stone (range varies from 87% of households in the lowest income class to 98% in the highest income range). Still, we may observe a positive association between the use of concrete-blocks and household income as some housing in the lower income classes use different materials (Figure 9). There is a low tendency in the lower income households to build the outer walls of the housing unit from wood.

These results need some clarification. In 2010, about 80% of households lived in a house, 17% lived in an apartment and respectively 2% and 1% lived in a remodeled (metal) sea freight container or in a shack. On average, in 2010, about 93% of these housing units were built from stone, 5% from wood, and respectively 1% and 2% of housing units were built from metal or another type of material. Only very few (often historic) wooden houses still exist today. The graph in figure 9 only shows part of the full range of used construction materials (x-axis ranges from 80-100%).

Concrete blocks thus, are the norm where the construction of outer walls is concerned. From discussions with local constructers we understand that most houses have no specific outer wall insulation, and there is also little knowledge about alternative construction designs or use of alternative materials/techniques to minimize heat transfer to the inside of the house. Often, the outer walls are sun-drenched. Concrete blocks do have a high thermal mass that is perfect for storing heat, but as most houses in Aruba are built from single layer ‘blokki’ (concrete blocks) the heat buildup during the day may become so intense that heat is radiated inside.

Figure 9 Relationship between household income and most prevalent material for the outer walls of the living quarter.
Note: the range on the lower axis is between 80%-100%. Thus as well in the lowest income class 87% of households use stone, concrete or bricks as major construction material.



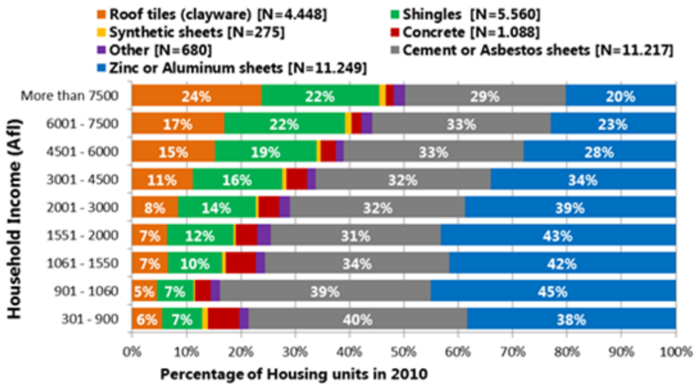


Figure 10 Relationship between household income and roofing material

In Aruba roof tiles and shingles are more present in housing units inhabited by households with a relatively higher income (Figure 10)[8]. Respectively, 24% and 22% of households with an income above Afl 7,500 per month live in a housing unit with a rooftop built from clayware tiles and shingles, whereas these percentages are as low as 6% and 7% for household with a gross income in the category Afl 300 - 900 per month. In the lower incomes, we find more often sheets of corrugated cement or asbestos plates, or zinc or aluminum sheets (up to respectively 40% and 38% of housing units). The vast majority of roof tops today are, however, covered with metal- or cement/asbestos sheets. In 2010, 4,448 living quarters used ceramic tiles as primary rooftop material against 5,560 that used shingles, 11,249 that used metal sheets and 11,217 that used cement or asbestos sheets.

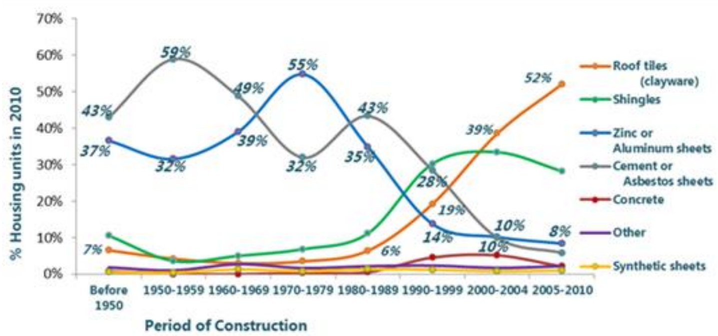


Figure 11 Distribution of type of rooftop material and period of construction of housing unit (Census 2010).

Not unexpected, we find a relationship between the presence of roofing material and the period of construction (Figure 11). Currently, the predominantly used type of rooftop material for new construction is roof tiles. We observe a shift in the material most often used for roofing when we compare the housing units from different periods of construction in 2010. During the 50s, a majority of houses were built with asbestos or cement roofing (in 59% of living quarters).

8 A positive or negative association between the variables household income and type of construction material explains the relationship and relevance of both housing characteristics with each other, but does not necessarily indicate a causal relationship.

Interestingly, again, during the 80s, sheets of asbestos/cement were used most frequently. We believe, however, that the two peaks in the use of cement/asbestos plates over time are a misleading consequence of the fact that a rather broad definition was used during the Census in 2010.

During the Census in 2010, the two types of rooftop materials, asbestos and cement sheets, were combined namely into a single category given that it would be impossible for the surveyors in the field to distinguish between the two. The second peak, during the 80s, may however be dominated by cement-sheets only because at the time information about the health risks to use asbestos was already well available. So, the use of asbestos during the 80s is less likely (UvAWeb, 2012).

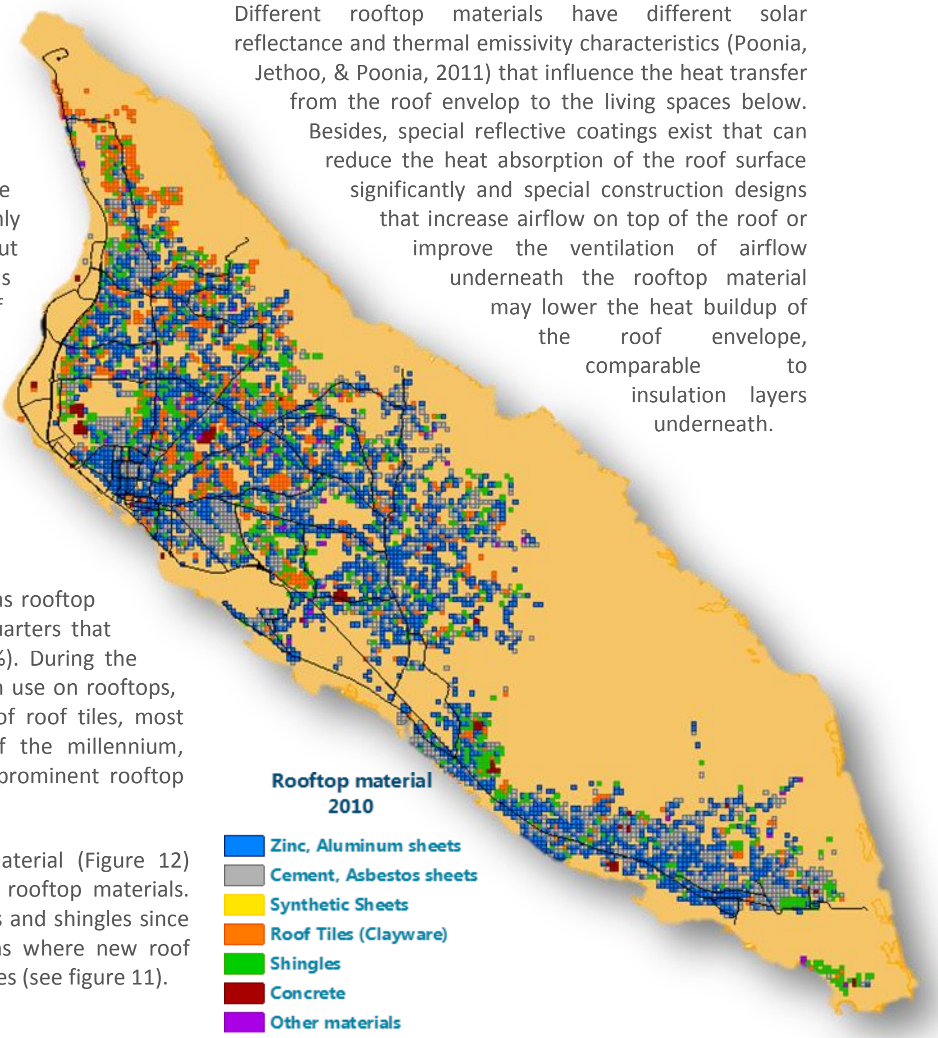


Figure 12 Spatial representation of type of rooftop material (Census 2010) based on the most prevalent rooftop material per 100x100 meter grid square areas. Source: Census, 2010.

The use of zinc and aluminum sheets as rooftop material is most prevalent in living quarters that were constructed during the 70s (55%). During the 90s, shingles were the main material in use on rooftops, but soon thereafter we see the use of roof tiles, most often from clayware. At the turn of the millennium, clayware roof tiles became the most prominent rooftop material in new house construction.

The spatial distribution of rooftop material (Figure 12) clearly reveals aggregations of similar rooftop materials. The increase of the use of ceramic tiles and shingles since the 90s elegantly reveals the locations where new roof construction took place in recent decades (see figure 11).

More air conditioning

Air-conditioning energy savings have become a topic in recent debate on how construction can help to become more energy-efficient, in particular in hot and dry climate zones[9]. Artificial cooling can be reduced considerably with roofing materials of higher solar reflectance and thermal emittance properties (Akbari, 2008), or, more generally, with a rooftop design that specifically allows for less heat transmission between the roofing envelop and the living space (Poonia, Jethoo, & Poonia, 2011).

To be exact, absorbed solar heat partly radiates inside from the rooftop and heats the air in the space below. When a lowered synthetic ceiling is placed beneath the rooftop, the space in between the rooftop and the ceiling acts like a buffer zone and keeps most (but not all) of the radiated heat during the day from entering directly into the living spaces below. This air pocket however does retain its heat also into the night, in particular when there is insufficient air flow and ventilation (which is often the case). As a result, at night, when the outside temperature drops, an AC in the bedroom needs to cool harder because the warm air pocket above the ceiling still transfers heat into the living space below. A brief introduction to the subject of cool roofs is given by (EPA, 2015)[10].

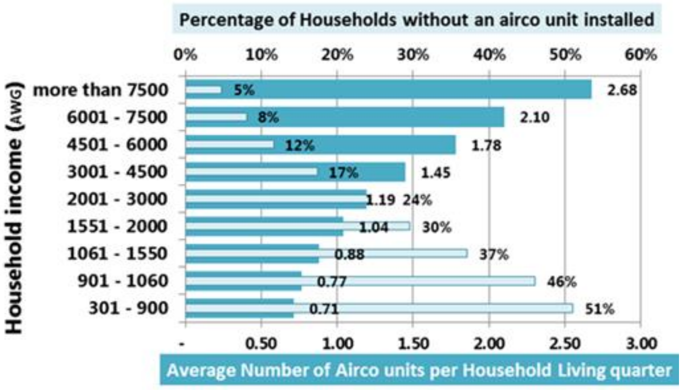
Different rooftop materials have different solar reflectance and thermal emissivity characteristics (Poonia, Jethoo, & Poonia, 2011) that influence the heat transfer from the roof envelop to the living spaces below. Besides, special reflective coatings exist that can reduce the heat absorption of the roof surface significantly and special construction designs that increase airflow on top of the roof or improve the ventilation of airflow underneath the rooftop material may lower the heat buildup of the roof envelope, comparable to insulation layers underneath.

In Aruba, many rooftops have corrugated metal sheets from zinc or aluminum or asbestos/cement-based sheets fixed to a wooden skeleton with often no insolating roofing panels underneath. This type of construction was affordable and became common practice for building houses during the 70s and 80s (see figure 11). Underneath the open frame was a lowered ceiling that protects the living space against intense heat buildup during the day. Temperatures in the space above the ceiling can rise to the extreme, which explains the need for ventilation.

[9] www.coolroofs.org

[10] www2.epa.gov/heat-islands/reducing-urban-heat-islands-compendium-strategies

Figure 13 Relationship between household income, average number of air conditioning units per household, and proportion of living quarters that have no working AC units at all (Census in 2010).



These types of dwellings are mostly well ventilated. However, new house constructions use ceramic tiles or shingles on top of closed wooden panels, and such houses are easier to insulate than those with rooftops of corrugated sheets on a wooden skeleton.

As a result, modern households frequently use the option to have their living area completely closed to the outside and invest in air-conditioned cooling (pers. comm. with local contractors) improving their comfort but also raising the demand for electricity during the day.

In order to create a more sustainable energy-efficient environment it is worthwhile to evaluate the relation between construction and design characteristics of *residential* housing units and the presence of installed (and working) AC-units. Figure 14 and 15 give an overview of the abundance of household air conditioning systems in Aruba in 2010.

The spatial distribution of the total number of air conditioning systems per 100x100 meter area (Figure 13) follows closely the spatial distribution of number of households, i.e. most air conditioning systems are found in and around the populated areas, in Oranjestad and the surrounding areas, in Noord, Bubali, and in Pos Chiquito and in San Nicolas.

However, if we correct these figures for number of housing units, the distribution reveals a different pattern (Figure 14). In some areas residents own an above average number of air-conditioning units. Areas such as Bubali, Klip/Mon Plaisir, Wayaca, Ponton, Palm Beach, Bakval, and Salina Cerca in Noord, have a relatively high prevalent number of AC units (above 2.5 AC units per household). In some of these neighborhoods the most frequent number of AC units is as high as 5 per housing unit. Figure 14 also shows that, in the center and direct surroundings of Oranjestad and more to the south, in the region San Nicolas and surroundings, we observe the opposite, the most prevalent number of AC units per living quarter is noticeably low (often less than 1.0 AC unit per household)[11].

A total absence of air conditioning systems occurs in 20% of cases in 2010 (Table 1), i.e. in one of every five households.

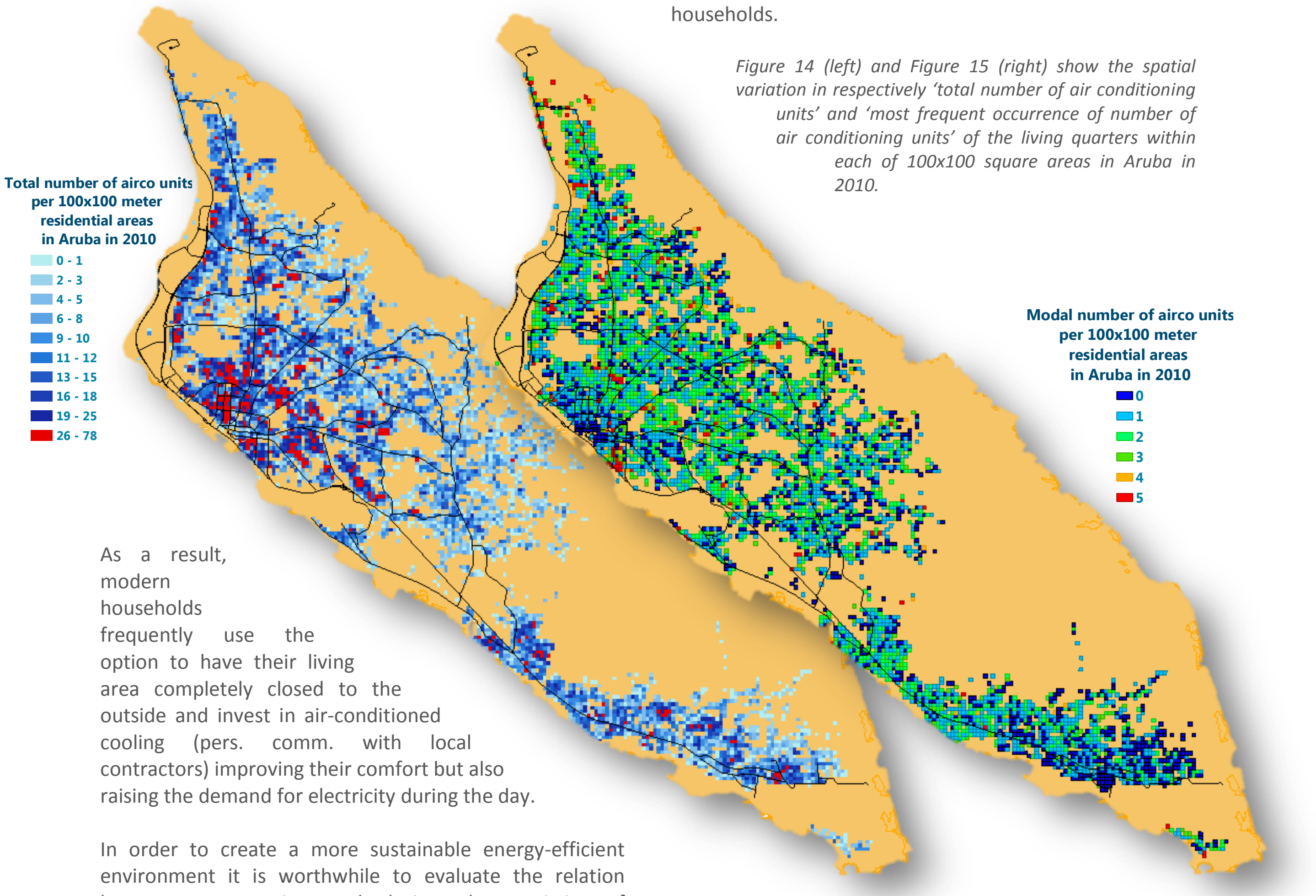


Figure 14 (left) and Figure 15 (right) show the spatial variation in respectively 'total number of air conditioning units' and 'most frequent occurrence of number of air conditioning units' of the living quarters within each of 100x100 square areas in Aruba in 2010.

[11] In the Census in 2010 and earlier Censuses, the question refers to the number of functioning AC units. Unfortunately, there was no option to ask for type of AC unit or BTU usage. In some cases, households may use a central air-conditioning system.

AC units/ HH	0	1	2	3	4	≥ 5	Total
%Households (HH)	20%	33%	25%	14%	5%	3%	100%

Table 1 Distribution of Households over number of AC units per household (source: Census 2010).

These households are spread all over the island albeit apparently somewhat more prevalent in the rural areas east of Santa Cruz and east of Noord towards the coast (Alto Vista and Calbas) and in and around Oranjestad and the complete surroundings of San Nicolas. Some of these locations will be more open and windy and may require less cooling, but in the majority of these cases, the housing units are situated in the city center or in more populated areas. Other reasons, such as low income may apply why occupants would not be able to afford an AC unit.

The importance of household income in regards to the ownership of air conditioning units is explained in Figure 15 in more detail. The variation in number of functioning air conditioning units per households ranges from 0.71 in the low income class (Afl. 300-900 per month) up to an average of 2.68 AC units in the high income class (above Afl. 7,500). The percentage of households that possess no air condition unit at all is highest (51%) in the lowest income class (Afl. 300-900) and lowest (5%) in the highest income class (above Afl. 7,500 per month).

Since the space that is most likely to be cooled at night is the sleeping area, we detailed the relationship between type of rooftop, number of working AC units and number of bedrooms per living quarter (Figure 16). Beyond 4 bedrooms per housing unit we have insufficient data for a comparative analysis.

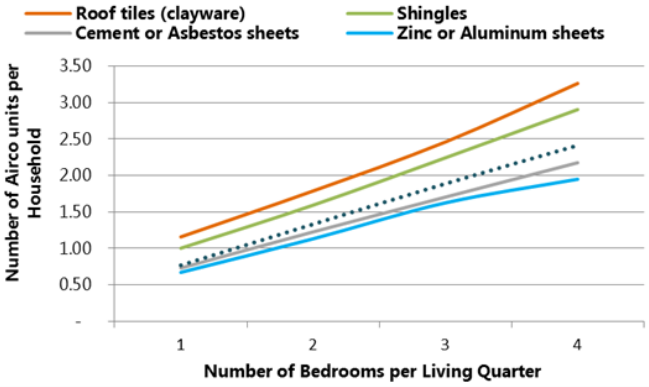


Figure 16 Average number of working air conditioning units installed per type of rooftop material and number of bedrooms in the housing unit in 2010. The dotted line represents the average irrespective of type of rooftop material.

On average, despite the positive relationship that more bedrooms relate to more AC units, the number of air conditioning units is almost always less than the number of bedrooms, irrespective of the type of rooftop material. Overall, however, living quarters with ceramic roof tiles have on average more AC units per bedroom than living quarters with shingles. Living quarters with shingles have in turn, on average more AC units than living quarters with a rooftop of asbestos or cement plates. The lowest number of AC units is observed when the rooftop is with zinc or aluminum sheets (Figure 16).

In figure 17 we present information about the relative distribution of living quarters with a given type of rooftop material per number of installed AC units.
We observe a positive association between the amount of working AC units and the presence of *ceramic roof tiles* and *shingles* and a negative association between the amount of working AC units and the presence of *zinc or aluminum sheets* or *asbestos or cement-based sheets*.

Housing units with 5 or more AC units installed have in 32% of cases a rooftop with ceramic tiles and in 24% of cases one with shingles, but in housing units with only one single AC unit installed, these figures are, respectively, 9% and 15%. In contrast, in housings with 5 or more AC units installed 18% are with zinc/aluminum sheets as rooftop material, and 21% have asbestos/cement-based sheets, whereas these proportions are as high as 38% and 32% in situations when there is only one single AC unit installed. In households that have no working AC unit at all, the rooftop material is even more often with '*zinc or aluminum*' and '*cement or asbestos*' sheets (respectively 44% and 36%).

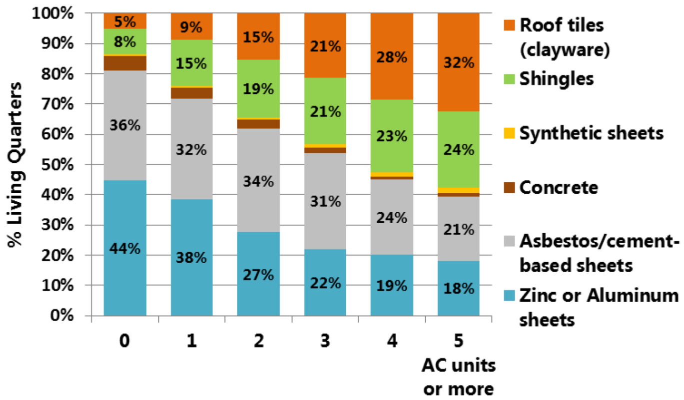


Figure 17 Proportion of living quarters per number of air conditioning units installed for type of rooftop material (Census 2010).

It is, however, difficult to interpret our findings in terms of necessity to install more or less AC units for the mentioned rooftops. Firstly, not only the type of roof materials, but also the type of roof designs, i.e. the complete roof envelope and house construction, determines the amount of heat transfer into the living space. Unfortunately, the Census did not provide information about the design details of the roofing envelop in Aruban housing units, so we have insufficient data to analyze this aspect.

Furthermore, the information presented in figure 10 shows a strong association between the use of ceramic tiles or shingles and higher income households. A similar positive relationship is shown in figure 15 and exists between number of AC units installed and household income. Understandably, higher income households can afford not only more AC units, but can afford also a more durable and attractive roof type with adequate insulation that will also allow a more energy-efficient use of the AC units. Nevertheless, in Aruba, most households still have rooftops from zinc/aluminum sheets or asbestos/cement-based sheets and have relatively fewer AC units.

Towards a more sustainable living

In a previous study (Derix, 2016d) on the suburbanization of the Aruban countryside we highlighted the increase in housing units in particular during recent decades and the spread of buildings across the island in association with spatial economic developments. Here, we elucidate some of the trends that can be recognized in building construction and housing characteristics.

The trend in housing units in Aruba appears to shift towards a smaller built-up surface area, fewer rooms and more than a single floor level. We observe a range in housing characteristics that vary with total household income. Higher income households tend to have a larger built-up space, completely fenced terrains and more frequently use stone, concrete or bricks for the construction of the outer walls as well as ceramic tiles or shingles as rooftop material.

These trends reveal a direction towards smaller living spaces in a denser built-up environment. As this trend is likely to persist, this may have consequences not only for a loss in remaining landscape but also for the 'suburban' micro-climate in and around our living spaces. Despite the fact that many of the housing units in the dense city center of Oranjestad and San Nicolas are relatively small and often without AC unit, the total number of residential AC units in these areas still is very high. Given the presence of many businesses that use AC units during the day, it becomes obvious that local micro-climate conditions will spiral towards a less favorable ambience like predicted by the '*heat island'* [12] effect ((Bharat, 2009) (EPA, 2014) (Golden, 2004)). We lack specific information about whether a heat island effect exists in Aruba, but it is safe to assume that with the increase in construction and suburbanization (under the tropical climate regime), there will be higher local micro-climate temperatures, due to the absence of the cooling effect from winds, and, shade or evaporation from vegetation.

Consequently, this suggests a reinforcing feedback loop towards an increased energy-demand for air-conditioned cooling.

From an environmental point of view and in terms of improving energy-efficiency[13] most (AC-related) gain can be made with improvements in the thermal characteristics of the total roofing envelop of housing units with zinc/aluminum or asbestos/cement-based sheets, simply, because these types of roofs are the most prevalent in the urban as well as in the suburban and rural areas (despite a current trend towards the use of ceramic roofing).

However, the households involved probably cannot afford costly structural roofing improvements. Recent studies, such as by Alvarado & Martınez (Alvarado & Martınez, 2008) and Miller et al. (2012) focus on alternative cost-effective means to improve the thermal properties of the roofing envelope.
Because of the high material costs involved, it is relevant to search for and support alternative approaches on how to cool the inside home environment in particular in lower income households that lack the means to invest in energy-efficient rooftop constructions.

Energy-efficient construction standards and designs as well as projects that attempt the greening of the suburban environment already have become common practice in several countries abroad[14]. Some approaches deserve wide recognition, such as more sustainable spatial urban planning with shady vegetation to alter the local ambient circumstances (and increase evaporative cooling) and the use of reflective coatings, insulation or the placement of additional roof or wall panels that create shadow on the sunlit parts of the outer house envelope. Also, alterations that improve air ventilation along the inner or even outer roof surface will minimize the level of heat buildup and improve living conditions as well as reduce costs for artificial cooling.

In an effort to become more sustainable it is relevant to gain insight in the distribution of energy-consuming living standards. In this paper, we analyzed some trends in housing characteristics in Aruba to illustrate the changes that have taken place in how we live and how we change our direct surroundings. We linked information about construction and housing characteristics as well as the use of air-conditioning systems in order to give insight in what privileges we attempt to pursue on the road to sustainability and energy-efficiency.

[12] From EPA: Referenced by *Bharat* (2009) 'Heat islands form as vegetation is replaced by asphalt and concrete for roads, buildings, and other structures necessary to accommodate growing populations. These surfaces absorb – rather than reflect - the sun's heat, causing surface temperatures and overall ambient temperatures to rise'.

[13] *Only very recently energy-efficiency is put back high on the agenda, not because there is a lack in energy but because the global climate is turning erratic.*

[14] http://www.epa.gov/greenbuilding/standards

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Landscape series: 6

Inconveniences in the home neighborhood in Aruba

*"Typical wildered open cacti-scrub landscape
Overgrown by grasses: former agricultural Cunucu"*

Photo: Ruud Derix, 2003

The Aruban landscape has undergone many changes in history. This paper is part of the landscape series:

"Spatial Developments in the Aruban Landscape: A multidisciplinary GIS-based approach derived from geologic, historic, economic and housing information"

2016

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2016

This paper is part of a series on the developments that relate to the Aruban landscape. To bring into perspective the current environmental threats and developments, we review aspects of inconveniences that Aruban household members experience within the direct neighborhood of their living quarter. We call the circumstances that surround these inconveniences conflict situations. Insight in conflict situations that relate to the local environment is vital to understand the effect of for instance urbanization and other socioeconomic developments on wellbeing and the developments in land-based and marine ecosystems.

At the basis of tourism in Aruba lies the natural beauty of coastal waters and ecosystems. Few people, however, understand that the quality of the coastal land arises not just from geological inheritance, but that it is dependent on present-day processes on land and at sea, and, that the crystal clear waters and fauna-rich marine ecosystems depend on a very delicate environmental balance between land and sea. It is a cynical truth that the success and economic developments on land undermine the quality of these ecosystems, posing a threat to nature and, therefore, also to tourism exploitation itself.

Economic developments come with human interference, habitat destruction, pollution and waste. In the limited availability of space on a small island like Aruba, sustainability is built on the delicate relationship between occurrences on land and at sea, i.e. changes in the landscape and environment are influenced by changes in the socio-economy and vice versa. Sustainable management requires anticipation and fine-tuning of current general knowledge. What makes "*calibrating*" actions a challenge is that the effects of human impacts partially remain hidden and accumulate until the threshold level is surpassed at which the effects become apparent. For instance, chemical pollution of groundwater and soils poses a risk to the environment and to public health with possibly long-term and costly consequences, but until it is significant the processes of chemical pollution are easily overlooked.

In this paper we will focus on the interface between the economy, society and the environment, where the results from human economic action start to bounce back on the wellbeing. First, we will focus on the apparent inconveniences at *home* in respect to the *local neighborhood.* Home is considered the place in which we experience most of our quality of life and where we are meant to experience the security of a shelter. Next, we will investigate some of the more 'hidden' processes in the environment that accompany economic development and that may not yet be in tune with our efforts to attain sustainable living.

Inconveniences in the home neighborhood

The spatial analysis of inconveniences that are experienced in the neighborhood of households can provide insight in the distribution of potential risks to environmental and public health. A higher spatial resolution of the mapping of residential concern pinpoints areas of conflict that otherwise may remain unnoticed (Leonard, Caughy, Mays, & Murdoch, 2011). This is what we intend in this study. The Census in 2010 included questions about how household members valuated the surroundings of their living quarter. The primary question was: "*Do you or more members of the household, experience any inconvenience in your immediate environment from…*..example 1, example2, etc."

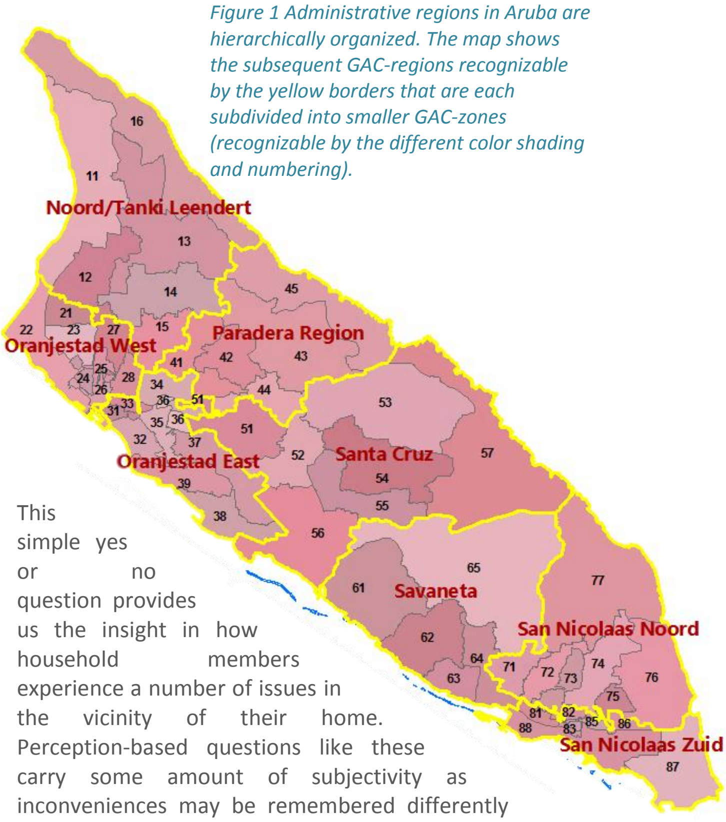


Figure 1 Administrative regions in Aruba are hierarchically organized. The map shows the subsequent GAC-regions recognizable by the yellow borders that are each subdivided into smaller GAC-zones (recognizable by the different color shading and numbering).

This simple yes or no question provides us the insight in how household members experience a number of issues in the vicinity of their home. Perception-based questions like these carry some amount of subjectivity as inconveniences may be remembered differently dependent on circumstances and timing. It is a strong argument, however, that something may be out of the ordinary when several households in the same neighborhood share a similar perception. Similar questions were asked in earlier Censuses, thus we can compare the spatial distribution of inconveniences over several decennia. Methodologically, however, a comparison between years, is only possible at the level of GAC-zones[1], i.e. at less spatial detail (Figure 1) since the GAC-zone is the highest level of detail that both the Census in 2000 and 2010 have in common. Moreover, due to the large surface extent of some zones it is difficult to link findings to local spatial characteristics at a finer spatial detail.

[1] The Geographical Address Classification system (GAC, 2012) is an administrative system of classification that was developed in Aruba for the purpose of information analyses. Its hierarchical structure enables users to present information at three different administrative levels. The GAC-system divides Aruba into 8 regions (see figure 1). Each of these regions is divided into a number of zones. Each zone consists of a number of streets or neighborhoods that however cannot easily be displayed as a surface area since the addresses do not fall exclusively in a specific area but overlap in space. A few zones (in particular along the Northeast coast) still remain largely unpopulated.

Therefore, in 2010, in preparation of the Census, we anticipated that we should be able to perform data analysis preferably at a higher spatial resolution. To overcome the lack of spatial detail we were able to aggregate and disseminate, in compliance with the rules of privacy protection, the point-based Census information at the level of GAC-zones, as well as at the level of a range of grid-tessellations with smaller square areas.

Environment issues that cause inconveniences at home

We reviewed if households experience inconveniences from 'dust', 'air pollution', 'noise', 'traffic', 'flooding after heavy rains', 'litter and accompanying stench', 'car wrecks' and 'stray dogs'. Some households refrained from participation in response to these types of questions (between 0.5% and 0.7%).

Dust is caused by the dry climate and constant (Northeast Trade) winds and is a common problem in Aruba, particularly in the more open areas. Households were asked specifically about whether they experienced some inconvenience due to an excess of dust, caused for instance, from *excavations*, *dirt roads* or *new construction* nearby. In similar fashion we asked about air pollution[2], exemplified as inconvenience for instance from *stench, exhaust fumes, soot, etc*., about noise, exemplified as sound hindrance from *airplane traffic or neighborhood nuisance*, about traffic, exemplified as inconvenience from *unsafety or other traffic related activity*, and about litter, exemplified as inconveniences from *dumped litter* or *such activities* in the direct neighborhood of the living quarter.

Inconvenience from	*Dust*	*Noise*	*Air Pollution*	*Flooding*
N zones with a decrease in inconveniences	*49*	*30*	*15*	*9*
N zones with an increase in inconvenience	*0*	*19*	*34*	*40*
Total GAC-zones	*49*	*49*	*49*	*49*
% of zones with a decrease	*100%*	*61%*	*31%*	*18%*
% of zones with an increase	*0%*	*39%*	*69%*	*82%*

Table 1 Number of GAC-zones where there was an increase (worsening situation) or decrease (improvement) in the percentage of households that experienced the specific inconvenience in their household neighboorhood in 2010 in comparison to the situation in 2000.

Comparison between the data of 2000 and 2010

In table 1 we summarize at the level of zones, changes between the 2000 and 2010 with regard to inconvenience from *dust, noise, air pollution* and *flooding.* A distinction is made per GAC-Zone whether there has been an increase or a decrease in the proportion of households that expressed their respective inconveniences in 2010 as compared to 2000.

[2] The US Environmental Protection Agency distinguished six major sources of Air Pollutants: Carbon Monoxide (CO), Lead (Pb), Nitrogen Dioxide (NO_2), Ozone (O_3), Sulfur Dioxide (SO_2), and Particulate Matter (PM_{10} or smaller).

The results show that the proportion of households that indicated to experience inconvenience from *dust* dropped within *all* GAC-*zones*. This does not imply that households do not experience inconveniences from dust anymore in 2010, but suggests that there has been a positive change towards improvement in how household members experience the direct surroundings of their home with regard to nuisance from dust. In regard to *noise* the situation appears to have improved in 61% of all zones.

In contrast, with regard to inconvenience from *air pollution*, that was exemplified by stench, exhaust fumes, or soot in the direct environment of the home, the situation worsened in 69% of all zones.

Similarly, inconvenience from *flooding after heavy rainfall* worsened in 82% of all zones in 2010 compared to 2000.

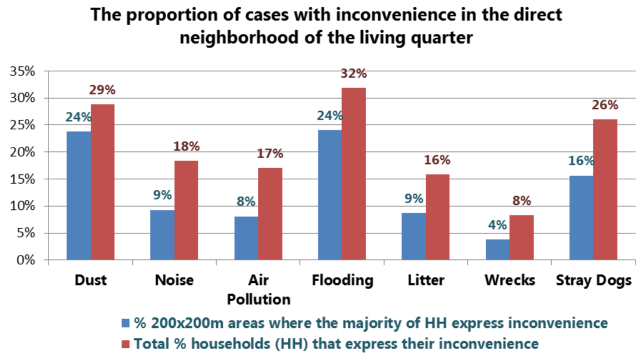


Figure 2 Relative level of inconveniences in 2010 per type of inconvenience and distribution over the 200x200m residential areas.

Prevalency in 2010 across 200x200 meter grid

We researched the occurrence of inconveniences from dust, flooding, litter, air pollution, noise, car wrecks, and stray dogs in more spatial detail at the level of 200x200 square areas to be better able to discern whether the inconvenience is concentrated in a specific area or whether the phenomenon is more common and occurs in all corners of the island. As the visualization by grids is a new and more recent method, only the data from the Census in 2010 could be used for this analysis. The local concentration of prevalent grid cell areas, i.e. 200x200m area in which more than 50% of households experiences inconvenience, reveals additional emblematic information on visual inspection of the map representation.

First, we analyze the spread of inconveniences, expressed as the proportion of inhabited 200x200m square areas where we observe prevalence (figure 2).

We noticed that the proportion of households that expressed some level of inconvenience was relatively high. For instance, inconvenience from *flooding* was expressed by 31.8% of all households and represents almost a quarter (24%) of all inhabited 200x200m areas.

Inconvenience from *dust* and *from stray dogs* was similarly reported, i.e. in respectively nearly one out of four (24% of inhabited space) and one out of six (16%) 200x200m square areas. Other kinds of inconveniences were much less widespread, such as inconvenience from *noise*, *litter, car wrecks* or *air pollution* (in respectively 9%, 9%, 4% and 8% of the inhabited square areas). Yet, prevalence in inconvenience in one out of every ten 200x200 m areas is still considerable.

Following, the areas where the majority of households (categorized as 50-75% and 75-100% of all households in the area) expressed their inconvenience is spatially visualized in the maps in figure 3c-g. We will discuss each of the conflict situations in more detail, next. The occurrence of inconvenience from *flooding after heavy rainfall* is discussed in a separate section in this paper.

Dust

Dust originates from solid particles (particulate matter) that primarily come from the soil, carried by the wind by human activities such as from construction and land clearance, traffic on unpaved residential roads, or, from the use of off-road vehicles on nature trails. Dust may also come from sea salt, pollen, spores, and tire particles as well. Small airborne dust particles are inhalable and can be carried long distances by the wind. Large particles from fugitive dust easily settle on the ground or rest on the vegetation where it cloaks and suffocates the foliage. Smaller particles (PM_{10} or smaller[3]) usually remain airborne for a while and when inhaled can cause diseases in the lower respiratory tract or in the lungs (Brunekreef & Forsberg, 2005).

Dirt and gravel roads are capable of producing large amounts of dust that can affect not only the vegetation and health, but even the chemistry of adjacent soils (Brown, 2009). Therefore, it is very relevant to evaluate the type of gravel and sand that is used on dirt roads (Kupiainen, Tervahattu, & Räisänen, 2003). Although the chemical composition of the dust particles play a role, its small particle size and the ability to be inhaled deeply into the respiratory tract defines the presence of small dust particles as a serious health risk factor, particularly in circumstances of prolonged exposure. Monitoring the concentration of PM_{10} and smaller particles (PM_5 and $PM_{2.5}$) is an important aspect in health programs. The ambient airborne PM concentration thresholds are commonly regulated under national health and safety codes (Pope, 2000) while internationally the UN/EU have set more general regulations to safeguard public health (unece, 2012).

The definition of dust may not be 100% robust to misinterpretation (EPA, 2015). Technically, we defined dust during the Census as *fugitive dust that* originates from soil. If dust incorporates small particles from combustion such as car exhaust with high carbon content, even if it can cause soiling, this is technically referred to as *air pollution*.

We explained the definitions that we used during the Census in 2010 by examples, however, we cannot be 100% sure that there has not been some confusion[4] between *dust* or *air pollution*. The data show the presence of inconvenience from *air pollution* along some of the main roads as well. This may correctly be considered attributable to the perception of small *particulate matter* from car exhaust, but it may also come from small *particulate matter* caused by the vehicles that swirl up dirt or particles from abrasion of the surface of roads and tires.

Our study shows (Figure 3d) that nearly a quarter (24%) of all households experience inconvenience from dust in the surroundings of the living quarter. In general, inconvenience from dust appears widespread in Aruba and is absent only in or near the dense populated centers of Oranjestad and San Nicolaas. The spatial pattern of households that experience inconvenience from *dust* reveals some small areas and a single larger area of particular concern, i.e. in the north in Aruba.

We lack adequate information about what exactly causes the dust (excavation sites, dirt roads, construction sites, etc.). In particular the northern region has been under construction during the recent decade and many residential roads remained unpaved. It is likely that in this region nuisance from the windblown sand and dust may be caused by the fine-grained gravel of sandy dirt roads and the combination of Northeastern Trade winds.

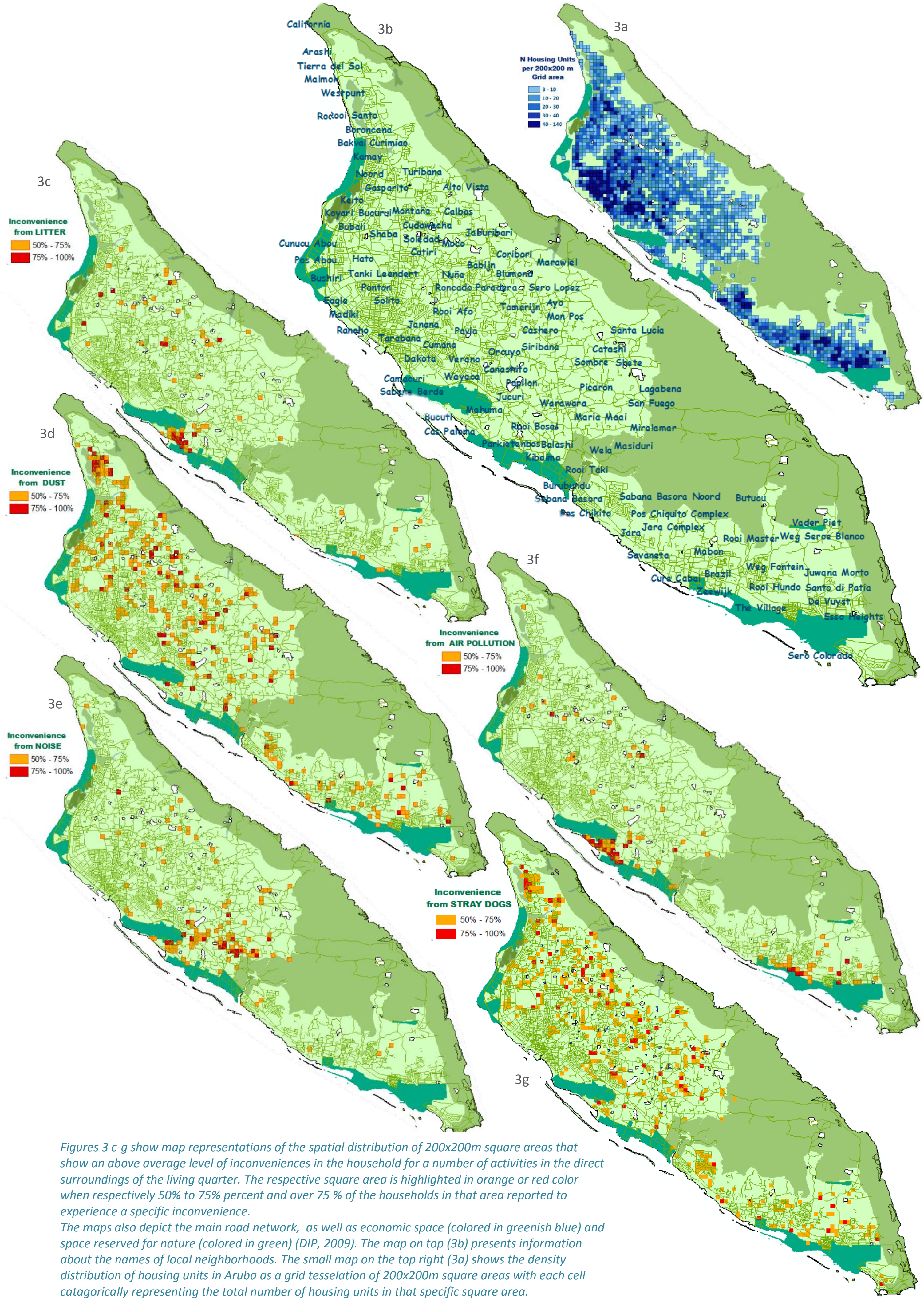
Noise

Inconvenience from noise occurs near the Reina Beatrix Airport (Figure 3e). It goes without saying that the departing and arriving planes may cause hinder from noise for those who live near the airport. Some concentration of areas with prevalence for inconvenience from noise occurs along the main road network. Worth mentioning is also the intense traffic in these locations, which may be the main cause of noise inconveniences. Inside residential neighborhoods inconvenience from noise may arise as well, for instance when the residential road serves as shortcut between different localities. A comparison between the maps of *inconvenience from noise and inconvenience from traffic* (Derix, 2013) indeed shows some concurrence along a few small roads within residence neighborhoods and suggests the existence of a road shortcut at these locations.

Inconvenience from noise does not only include inconvenience from the sound of airplanes or traffic, but may come from other sources of nuisance within the neighborhood as well. Inside residential areas we recognize ‘hotspots’ where households express their inconvenience from noise that is unlikely caused by traffic. In such cases there may be a local different source of hindrance, such as for instance ‘loud’ neighbors or business activity.

[3] PM_{10} is particulate matter with an average diameter size of 10 microns. This type of particulate matter is considered likely to be able to be inhaled and reach into the respiratory tract. PM_5 and $PM_{2.5}$ are considered likely to be able to be inhaled and reach into the respiratory tract as well as deeper in the lungs.

[4] Generally speaking, small particulate matter is a type of air pollution but commonly and also so during the Census in 2010 one specific type of small particulates, fugitive dust is considered as a separate category; in our case to be able to label inconveniences from dust from traffic on unpaved roads. The EPA defined Fugitive emission as particulate matter that is generated or emitted from open air operations in contrast to emissions that passes through a stack or a vent)



Figures 3 c-g show map representations of the spatial distribution of 200x200m square areas that show an above average level of inconveniences in the household for a number of activities in the direct surroundings of the living quarter. The respective square area is highlighted in orange or red color when respectively 50% to 75% percent and over 75 % of the households in that area reported to experience a specific inconvenience.

The maps also depict the main road network, as well as economic space (colored in greenish blue) and space reserved for nature (colored in green) (DIP, 2009). The map on top (3b) presents information about the names of local neighborhoods. The small map on the top right (3a) shows the density distribution of housing units in Aruba as a grid tesselation of 200x200m square areas with each cell catagorically representing the total number of housing units in that specific square area.

Air pollution and Litter

'Simeon Antonio', 'Bucuti', 'Cas Paloma' 'Parkietenbos', and to some degree also 'Mahuma' are adjoining localities that are situated just south of the Reina Beatrix Airport, near the public dumpsite and near businesses that use heavy road equipment. These neighborhoods are of particular concern as a majority of households express their inconvenience from noise (Figure 3e) and more so air pollution (Figure 3f) and litter (Figure 3c).

A large open waste dumpsite situated at Parkietenbos is likely to be one of the causes of the inconveniences experienced by neighboring households. More recently, a waste *separation* plant[5] was constructed at 'Parkietenbos', but the open public dumpsite is still operational.

Air pollution is an issue in households situated south of the airport but also near the oil refinery in San Nicolas (Figure 3f).

Abandoned excavation sites may serve as legal *(*RWZI-dumpsite in Wayaca) or illegal dumpsites (dumpsite at Sero Lopez). Both are frequently used as a source for litter, waste and other types of local disturbance in the surrounding areas*.* Similar in size as the excavation site in 'Mahuma' (currently closed) is a site at Alto Vista, in the northeast, and in the area of 'Weg Fontein', north of San Nicolaas. In both areas we observe heightened levels of inconvenience by households from litter and stench.

Stray Dogs

The main map in figure 3 shows the locations where hinder exists caused by stray dogs. Examples are found all over the island, but more so in the more rural regions and less in the city centers of Oranjestad and San Nicolas. In the region of 'Westpunt', east of the saliñas[6] in the north, and in 'Sabana Basora' and in a number of small locations, we observe a concentration of inconvenience from stray dogs. In 1989 (Sprang & Quant, 1989) an inventory survey of dogs and cats was conducted in Aruba. The study was repeated in 2003 (Rossen, 2003). In 1989, the researchers found that one in three dogs had regular access to roam free outside the compounds, compared to about one in four dogs in 2003. In 2003, one in every twenty dogs had full access to the street at any time of day. Almost two thirds of households owned more than one dog. The relatively high density of residential dogs is in line with the level of hindrance in 2010 that is spatially represented in figure 3g.

In 2015 new legislation was implemented to assure that households keep their dogs inside their own premises. The effort was to prevent hinder from free roaming residential dogs that disturb/attack pedestrians and cyclists.

Stray dogs are still a common sight, however. Mostly, these are abandoned dogs.

[5] Waste to Energy Plant

[6] The saliñas are the coastal wetland areas that still exist in the Northwest, but that have been blocked from the sea by tidal barriers and road infrastructures. At current, the brackish floodplain areas still show the characteristics from vegetation's adaptation to salinity and the presence of typical (migratory) bird species.

Soil enrichment, land-based pollution and rainwater runoff into the marine waters

Hidden disruptive processes in the environment

Little is known by the public about the Caribbean Sea which is under continuous stress from eutrophication and pollution. On the scale of regional polluters the position of Aruba has changed drastically in recent years, but the small island setting allows very little margin for error.

After the closure of the oil refinery in 2012, the direct environmental impact from pollution from the refinery activities ceased, but the consequences of earlier pollutive actions are still present[7]. Locally, in San Nicolas, and in the near region, problems still reside in the soils (Ridderstaat, 2007).

Today, pollution confines to small-scale industrial activities such as from the processing of salt water at the local water desalinization plant, from the leakage of the open dump site south of the Airport, from the traditional household cesspits, in particular in the coastal regions (that leak wastewater into the groundwater), and from the seasonal rainwater runoff into the sea. Many local cesspools near the coast situate on permeable Limestone Terraces and are traditionally made from bricks and not sealed at the bottom.

Hydrogeological/chemical studies (Finkel & Finkel, 1975) (Borst & de Haas, 2005) have emphasized the importance of freshwater retention sites to limit erosion and improve the formation of soils for agriculture and vegetation. Long-term monitoring studies of pollution and nutrient-enrichment in the neighboring islands Bonaire and Curaçao stress the impacts of daily pollution and eutrophication on the near shore coastal ecosystems and the lack of adequate sewage treatment plants that may prevent the sewage water to reach the sea (Lapointe & Mallin, 2011) (Goreau & Thacker, 1994). A proper water management on land is relevant for the maintenance of a healthy living environment on land as well as at sea.

Studies show that marine and terrestrial ecosystems in the Caribbean have difficulty with high levels of nutrient enrichment and thrive best in a nutrient-poor balance of state (Siung-Chang, 1997). In the worst case scenario, a nutrient rich coastal water stimulates microalgae growth (Lapointe e. a., 1998) and may create oxygen deprived zones. Under such circumstances, water becomes turbid (Goreau & Thacker, 1994) and coral communities, mangroves, and sea grass beds will suffer severe damage (UNEP, 2015). Other markers of a disrupted marine ecosystem are the lessened presence of predator fish that may trigger a population explosion of, for instance, jellyfish. It is without saying that even a small change in this direction may have a negative impact on the tourism industry.

The unforgiving disruptive enrichment by nitrogen and persistent/bioaccumulative substances of the nutrient-poor (oligotrophic) highly sensitive local marine ecosystems happens in an encroaching slow but devastating rate (Greenpeace.org, 2015), (Worldwatch, 2000) (Goreau & Thacker, 1994).

[7] http://www.oceanhealthindex.org/Countries/Aruba/

The contamination and enrichment of soils from household liquid waste and sewage may by itself be mild at any given moment but constituents accumulate in the soil and groundwater on a continual basis (Sharpley A.N., 1996). For instance, an alteration of the soil chemistry and acidification of the topsoil[8] is described from the local disposal of household waste, such as paints, detergents, oils and leaking batteries (Pimentel, 2005).
What happens next is that when soil constituents lose their binding capacity, nutrients such as nitrates, phosphates and urea find their way more easily from the groundwater into marine waters. Similarly, bio-persistent contaminants such as pesticides, heavy metals and household chemicals accumulate and seep into the deeper soil layers and groundwater and cause harm in the food chain at a large distance from their actual disposal site.

Next, we reveal some insight in the 'hidden' underlying process of infiltration of contaminants and nutrients into the natural surroundings and describe the role of typical geological and societal local circumstances.

The disposal of "eye-catching" municipal solid waste is recently well-organized, but the disposal of liquid waste still needs more attention. We have to gain information and grow awareness that helps to overcome and remove the solved substances of pollution and nutrient-enrichment before these can cause harm at sea.
In short, at the regional level, the processes that are less eye-catching but create accruing stress to the local marine environment are:

- *Acidification of marine waters, for instance due* to rising atmospheric concentrations of carbon dioxide (CO_2) and the consequential absorption of the gas by the oceans.
- *Sea water temperature rise*
- *Contamination and nutrient-enrichment of groundwater, in particular on the limestone, and their effluence into the marine waters*

Acidification may come from (polluted) stormwater runoff from land-based (industrial) activities. Unfortunately, we lack information about seawater acidification from land-based activities. Its impact even at a regional scale, however, may remain low since there is little industrial activity in Aruba. Thermal pollution at sea may come from 'coolant water'. Sea water temperature rise is expected to have a detrimental effect on marine life, although the phenomenon is at present insufficiently understood (Sewlal, 2010).

The effluent of land-based sources on the coastal marine environment has not been studied thoroughly in Aruba. Effluence can occur via:

- *Groundwater*
- *Rainwater runoff*[9]
- *Direct discharge* along the coast
- *Landfill leakage*
- *Fall-out* at sea as pollutants are carried by the wind

Better insight in these processes is relevant and significant to be able to manage the quality of near-coastal waters (Goreau & Thacker, 1994). We give an example of the dimension of pollution that can occur via waste water.

The effluence of pollutants from liquid waste

The constant drain of nutrients (and bio-persistent toxic substances) from residential living and economic activities filtrates in part into the soils and feeds into the groundwater. These land-based constituents eventually disperse into the coastal marine waters and overload the nutrient-poor (oligotrophic) marine ecosystems.
It is obvious that the high population density and impact from new building and road construction puts the small scale natural island setting under increasing stress. New insights learn that the question of when and where to act has long passed. Several studies in the Caribbean (Lapointe & Mallin, 2011) (Peters, 1997) have documented the effect from land-based runoff, the leaking of landfills, and, the warm water effluence on coral reef growth, or, the harm it brings to mangrove ecosystems along littoral coasts. Comparative studies in Aruba are lacking, however, but similar situations do exist.

A troublesome local situation with limestone terraces along the coast

The total balance of nutrients and contaminants (fertilizers, oils, salts, pesticides and detergents) that reaches the coastal waters will show considerable seasonal variation due to the seasonality of heavy rains and rate of evaporation.
As noted before, the *geology of the coastal zone* in Aruba may play an important role in the dynamics of exchange between land and sea. Most of the inhabited land along the coast is from karstic and highly permeable limestone rock (Derix, 2016c). Rainwater from the land interior reaches the porous limestone terraces from where most of it seeps into the sea, subterranean, via the ground water, via the faults and fracture lines or more directly at the surface via the dry-river systems. During most of the year, however, evaporation is so high as to prevent the effluence from leaking cesspools on the Batholith to reach the coastal waters. This may even be the case for many cesspools that are situated on the limestone terraces. In opposite direction, when evaporation is very high during the dry-season, coastal groundwater saline levels may even increase due to infiltration from sea water (Finkel & Finkel, 1975).
In contrast to the presence of limestone geological substrate, the compaction of soils and the cementation of the urban landscape will prevent rainwater to soak into the

[8] Nitrogen from wastewater sewage (detergents and urea) is thought to influence the biochemical processes in the soil. While there is an acidifying effect (biochemical release of free hydrogen (H+) acidic ions against less hydroxyl (OH-) basic ions) from ammonium nitrogen (urea) in soils, the highly soluble nitrates percolate into the groundwater. Acid surface soil can also increase dissolution of limestone layers and can cause dangerous sinkholes in Limestone layers on land.

[9] For a general discussion of urban wastewater runoff we refer to www.environment.nsw.gov.au/stormwater/

soil and therewith increase the amount of urban pollution that is washed out with surface water.

So, the magnitude of the nutrients and contaminants that reach the sea may be constrained in time and place but also altered dependent on local circumstances.

Studies conducted in limestone areas in Italy show that in fact limestone is quite effective in the neutralization of wastewater nutrients, often already within a single km distance from the infiltration point (Masciopinto & Carrieri, 2002). Unfortunately in Aruba, the limestone rocks are only up to 2.5 km wide and situated directly at the coast. The chance that polluted groundwater will leak from the limestone into the marine environment is still likely.
Groundwater studies in Aruba (Finkel & Finkel, 1975) have focused on the potential reserves of drinking water for agriculture purposes. A baseline study exists, however, that focuses on anthropogenic influences on groundwater quality (Sambeek, Eggenkamp, & Vissers, 2000). The study reveals elevated concentration of nitrates in a number of wells on the island and suggests that this may relate to the presence of nearby cesspools. In particular, in areas where there is easy penetrable limestone, a*quifers* and *wells* will be more susceptible to infiltration by persistent organic compounds and bacteria or viruses from nearby cesspools and contaminated soils, than in other parts (Wolf, Nick, & Cronin, 2015).
Their findings stress that cesspools need to be able to withstand a period of flooding, in particular in the flood-prone areas, but more preferable, avoid any risk on leaking into the ground water from modern septic systems. Currently, in Aruba, there is a policy to allow only completely enclosed septic tanks for new construction, but the rule is not yet fully legally embedded.

Monitoring the discharge of nutrients and contaminants
To keep track of the amount of contamination and enrichment from liquid waste[10] that reaches the marine environment via ground- and wastewater runoff is a challenging task. In Aruba, coastal water samples are collected and analyzed with the purpose of regularly monitoring the quality standards of safe swim water. Studies from abroad show that the contamination and nutrients thresholds for safe swim water are actually insufficient to safeguard the quality of coral ecosystems (Goreau & Thacker, 1994). Besides, while the measurements occur along the shallow coastline, discharge into the sea may occur via groundwater springs that seep off the coast into deeper waters.

In the ideal scenario, we would like to monitor the spatial pattern and intensity of subterranean groundwater effluence in combination with the concentrations and geochemical interactions between local soil constituents and contaminants in Aruba. Such studies, when feasible at all, are very costly and may, therefore, never be performed.

[10] We define household liquid waste as wastewater with contaminants of oils or fats, paints, detergents, cooking oils or hazardous household liquids, etc.

An alternative objective, therefore, might be to combine information already gathered from elsewhere and distillate the ‘probably’ that similar situations may occur locally as well. For instance, a study in 2011 (Lapointe & Mallin, 2011) in Curacao and in Bonaire shows that in relation to maintaining a healthy deep and shallow reef ecosystem a number of contamination indicators have already exceeded threshold values. No such studies exist in Aruba, but given the relatively similar pressures from population and housing, and a well-comparable climate and geological condition, one may carefully consider whether in Aruba, similar contamination of marine waters may occur.
Furthermore, the monitoring of net imports and net exports already provide insight in the level of local usage of for instance fertilizers, pesticides, or, cleaning products, and, therewith, the detrimental impact from disposed chemicals and nutrients via water, land or air. Knowledge about the chemo-physical characteristics and interactions of contaminants with local soil constituents, in combination with local hydrological and geomorphological conditions, may be useful to model impacts.

To get an impression of the amount of chemicals that is disposed in the local environment, yearly, we show the *total yearly import* of *soaps*, *detergents, cleansers* and *fertilizers* (the respective export figures are generally low and have not been shown in the representation in figure 4).

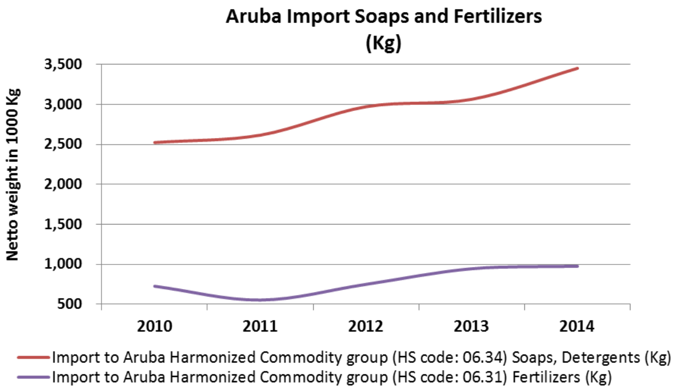


Figure 4 presents the weight import figures of respectively soaps, detergents and cleansers and of fertilizers, categorized by Aruba Customs Authority according to the Harmonized coding System[11] under category code 06.34 and 06.31, respectively.

In Aruba, in the absence of e central sewer system in most areas, soaps, fertilizers and pesticides are likely to end up in the garden soils and cesspools. The utilized substances will disintegrate and interact with soil constituents to become harmless substances, but part will accumulate in in the cycle of contaminated soil, ground- and effluent waters. On occasion, when disposed with the public waste stream the chemicals may be incinerated at the new local waste incineration plant, but we do not expect this to be

[11] CBS uses the International General Trade System for the processing and publication of all import and export data by commodities and by country. Total Imports and total export include all goods entering and respectively leaving the economic territory of Aruba. The economic territory of Aruba comprises of Aruba (the free circulation area) and the Free Zone Aruba. This is consistent with the General Trade System.

the case for most of the cleaners, pesticides and fertilizers. There is no separate waste collection stream for liquid waste products (except for some oils, fats and oil residues by restaurants and local car repairs, etc.).

Figure 4 shows a substantial rise (40%) in the import of *cleaning products* over the last five years (from 2.5 mio. kg up to 3.5 mio. kg per year). As most of these products will end into the soil we assume that there is a steady accumulation of phosphates and nitrogen in the soils that will eventually overload the binding capacity of soil constituents and wash away. Also, figure 4 reveals a rise in the import of fertilizers, be it in smaller quantities, up to 1 mio kg in 2014. We lack detailed local information about the effect of nutrients and (chemical) constituents on the oligotrophic local marine environment.

Uncontrolled effluence of nutrients and contaminants into the sea is influenced as well by local flooding after heavy rainfall and run-off into the sea.

Next, we will provide information about the level of incidental flooding after heavy rainfall, based on information gathered during the Census in 2010.

Incidental flooding

Local flooding carries a cost of damage to private and public property and infrastructure, causes accidents and inconveniences, and also poses a risk to public health.

Mostly, rain falls without causing extreme harm, but every few years, incidents occur when areas are flooded after heavy rainfall. To catch the incidental rainfall, rainwater dams (locally called 'Tanki') are built with the ability to overflow, but on one such occasion, unexpected damage to private property downstream occurred, when the rising mounts of water caused a breach in the Tanki outer wall.

In some areas, neighborhoods regularly suffer from the temporary inundation after heavy rains and inhabitants feel frustrated by the recurring events. New construction constantly changes the face of the landscape and changes the natural course of the rainwater. Sometimes small or even large dry-river waterways appear to be blocked completely. Later, when extreme rainfall occurs, the new homeowners in these neighborhoods get confronted with problems they were previously unaware of.

We analyzed the percentage of households that experience inconvenience from *flooding after heavy rainfall* in each of a 200x200 meter area. In *figure 5* we show the 200x200m square areas where over 50% of households experience inconvenience from flooding after heavy rains and refer to these as the *flood prone* areas. The data are from the Census in 2010. The maps also show the location of dry-rivers and the location of different watershed areas (*figure 5A*), the height topology (*figure 5B*) and the extent of the limestone layer near the coast. The location of the household draining systems is exemplified in more detail *in figure 5C and 5D* (CBS, 2010).

Coincidentally, the Census activities in 2010 took place during a period of intense rainfall.

Characterization of the flood prone areas

We mentioned already, that a relatively high percentage of households (32% in 2010) express experiencing inconvenience from *flooding after heavy rains* (figure 2). These households expressed inconvenience from flooding in nearly a quarter (24%) of all residential 200x200m areas. In 82% of the GAC zones, the inconvenience from *flooding after heavy rains* was expressed to be higher in 2010 than in 2000 (Table 1). This is an indication that the situation in the neighborhoods had worsened over the last decennium. The reason seems straightforward as the density of construction there increased over the years.

However, many of the flood prone areas are located on the Lower and Middle Terraces (Busonjé, 1974) along the coast. We typically would not expect flooding areas on a high permeable limestone substrate. The limestone is on average between 15 and 45 meters thick and rests on crystalline rock or on a bed of layered clays and sand. Furthermore, that close to the sea, the groundwater is only a few decimeters deep and not only the natural water runoff is slow in these low-lying areas, also the transmission speed[12] in the limestone is too slow to allow a rapid drain of rainwater. At a groundwater gradient of approximately 0.001 near the coast the transmissibility is calculated at about 1.1 mm/sec and 2.0 mm/sec at some distance more near the border with the crystalline Batholith (Finkel & Finkel, 1975). Transmissibility is known to become worse with soil compaction and subsurface obstruction as occurs, for instance from infrastructures and from the construction of hotels such as along the coast.

An exceptional high density of households that expressed inconvenience from flooding is located in the Northwest, south of Bubali Plas and in San Miguel (*Figure 5C*) and also in the Southwest, in Pos Chiquito and in Zeewijk (*Figure 5D*). Three other areas are worth mentioning, i.e. east of 'Kamerlingh Onne Straat' up to the 'De La Salle Straat' (in Oranjestad), in the area of Tanki Flip and in the area of Bucurui/Sabana Liber. Needless to say, there are other smaller spots where residents experience hindrance from *flooding after heavy rains*.

[12] Transmission is the passage of water through the substrate

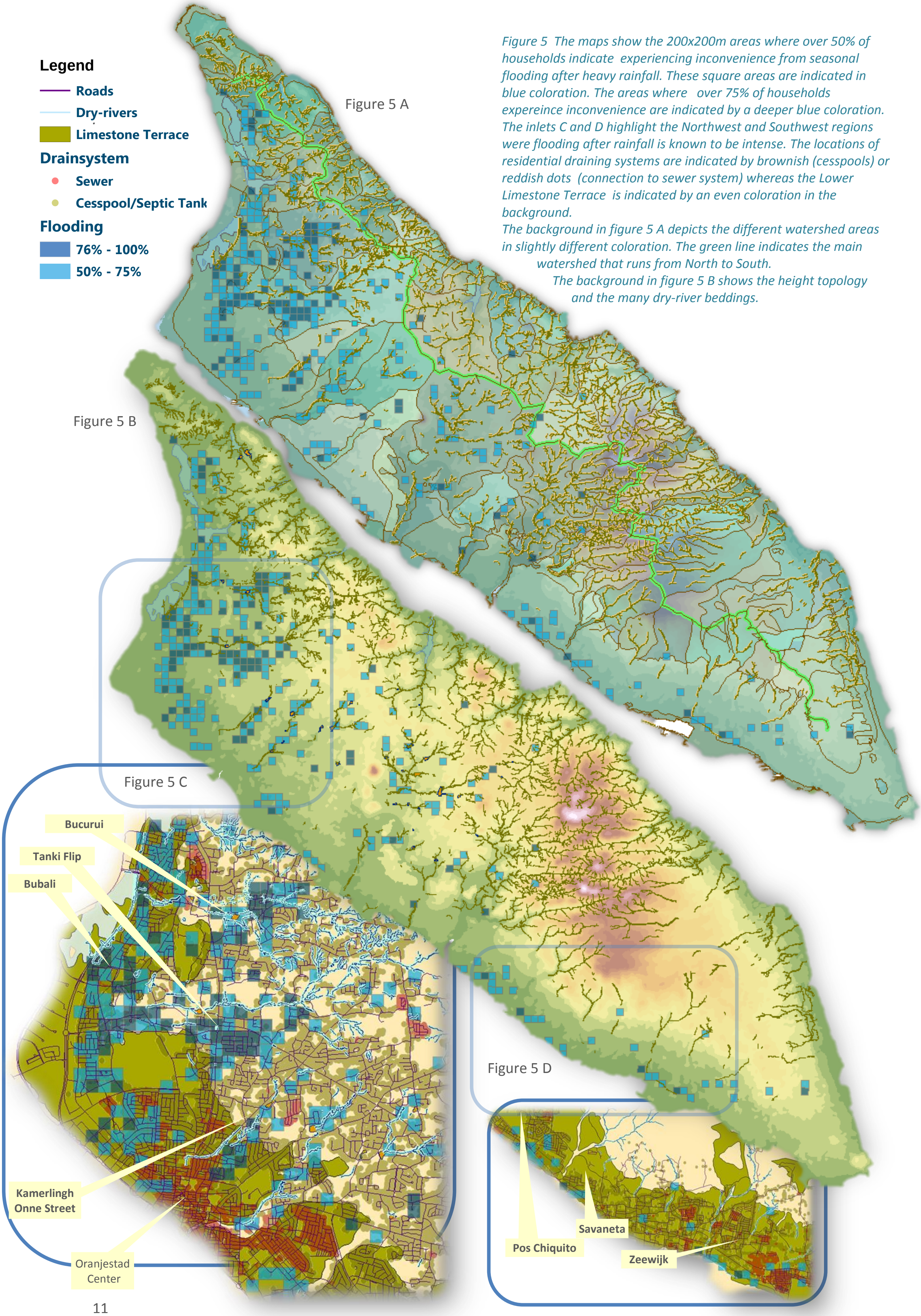


Figure 5 The maps show the 200x200m areas where over 50% of households indicate experiencing inconvenience from seasonal flooding after heavy rainfall. These square areas are indicated in blue coloration. The areas where over 75% of households expereince inconvenience are indicated by a deeper blue coloration. The inlets C and D highlight the Northwest and Southwest regions were flooding after rainfall is known to be intense. The locations of residential draining systems are indicated by brownish (cesspools) or reddish dots (connection to sewer system) whereas the Lower Limestone Terrace is indicated by an even coloration in the background.
The background in figure 5 A depicts the different watershed areas in slightly different coloration. The green line indicates the main watershed that runs from North to South.
The background in figure 5 B shows the height topology and the many dry-river beddings.

In an earlier paper on the geology of the landscape (Derix, 2016c) information from the Werbata map was discussed that outlines in fine detail the hydrological situation around the turn of the 19th into the 20th century. In 1911, Werbata already marked the strip along the coast north of Oranjestad and north of Savaneta as “flooded after rain”. Obviously, in absence of any housing, the area was considered unsuitable for inhabitation or for Aloe cultivation.

At the border between limestone terrace and batholith in the region of Bubali and Eagle, a number of (wind milled) wells pumped brackish and fresh groundwater to comply with the demand from the local population and their agricultural activities inland. Today, a local water sewage treatment plant (RWZI) is located next the small freshwater reservoir *Bubali Plas*. The saliñas that were present already a century ago also still exist, but as a result of land reclamation, drainage works, and weed invasion these wetland areas[13] are under continuous threat.

Drain problems for local housing projects seem to be solved with the construction of canals that improved the drainage and discharge of accumulated water to lower regions, such as in the area Madiki/Rancho (in Oranjestad) and in Pos Chiquito. In other areas such as in Bucurui/Sabana Liber the solution was more comprehensive and could not easily be solved by canalization since the area formed a local basin surrounded by infrastructure barriers.

A combination of size of the rainwater catchment area (background in Figure 5A), height topology (background in Figure 5B) as well as the type of geological substrate, type of plant cover or type of obstructions in the landscape define the likelihood of flood prone areas. Today the influence from man-made alterations to the natural course of the water adds to the topology of obstructions and causes some areas to suffer more than others.

For instance, the representation of watershed and height topology (Figure 5A and 5B) suggests a natural bottleneck in the low-lying area of Tanki Flip. In the same area, a large traffic junction with residential construction at all sides blocks the natural course of the water almost completely. The problem was largely solved with the construction of an artificial drain alongside the roads and traffic junctions (*see figure 5C*).

Similar low-lying areas exist *elsewhere* near the coast and more inland. A minimal difference in height may already suffice to slow down the natural drain of the rainwater, in particular when obstruction from housing development and infrastructure block the rainwater runoff.

[13] Both locations, the *saliñas* and the *Bubali Plas,* are recognized as important bird sanctuaries that play a role as important feeding and resting place for many migratory birds.

Flooding of cesspools[14] and septic water infiltration

The inlets C and D of figure 5 show a detailed view of the spatial distribution of private and public sewer systems (red colored dots) and cesspools (beige-colored dots) in Aruba in 2010 (CBS, 2010). The inlets demonstrate that in the majority of the areas that are prone to flooding, households possess cesspools/septic tanks (see *Table 2*).

In 2010, in total 31.8% of households expressed inconvenience from flooding after heavy rains and 36.8% of these households (18% of all households) are located in the 200x200m areas that we defined as *flood prone areas* (i.e. while over 50% of households expressed inconvenience from flooding).

N	%	Type of draining system
76	*1*	have NO private toilet
543	*9*	have a Sewer
5.393	*88*	have a Cesspool/Septic tank
68	*1*	have a Combination Sewer - Cesspool/Septic
11	*0*	have other type of drain such as a chemical toilet
45	*1*	Not reported
6.136	*100*	Is 18% from total number of Households

Table 2 Households that locate in a flood prone area[15]

From all the households in the flood prone areas, 9% had a sewer connection and 88% had a cesspool/septic tank (Table 2). Across the total population of households, about 19% is connected to a sewer and 76% have a cesspool/septic tank. Some households may have a combination of cesspool and sewer system or use a chemical toilet (this happens for instance when the living quarter is a trailer without a separate drain), although these are small in numbers.

Cesspools in Aruba are traditionally built of stone and are semi-open to allow sewage to leak into the ground. An additional chamber enables filtration of the sewage such that it can be used for irrigation in the home garden. This ‘grey’ water is unsuitable for watering vegetables and herbs that are meant for human consumption as the water may still contain parasites and bacteria. As *seasonal flooding* occurs in areas where there are many cesspools, there is a certain risk to public health when there are cesspools that leak to the surface waters when submerged. Phosphates, nitrates and contaminants easily dissolve into the surface waters and flow into the sea with the rain-water runoff, whereas the discharge and scruff that may carry parasites float and settle to other populated areas and attract disease vectors.

[14] A cesspool in Aruba is commonly a cemented underground chamber from blocks but semi-open to let the sewer water leak into the ground. Bacteria are important to decompose the solids, but quite often and unwittingly cleaners and detergents are disposed as well into the cesspool and this will kill the local bacteria. When decomposition of the discharges is incomplete and washed into the open there may be a threat to public health.

[15] A flood prone area is an area where over 50% of households in 2010 have indicated to experience hinder from flooding after heavy rains.

Geological unit *cf.* Busonjé	Sewer %	Cesspool/ Septic Tank %	Total %	N
Quartz-Diorite	***3***	***41***	***45***	**15,623**
Total Limestone	***16***	***36***	***54***	**18,937**
Deposit LT	*2*	*8*	*11*	3,675
Deposit MT	*11*	*24*	*37*	12,863
Erosion MT	*2*	*5*	*7*	2,399
Sub Total	*18*	*77*	*99*	34,560

Table 3 Percentage of households per type of drain system and type of geological unit in the most populated areas.
Source: Census, 2010 (CBS, 2010); map form Busonjé (1974).

We researched the proportion of cesspools on the limestone and on the Aruban Batholith. Differences in the composition of the substrate on the limestone and on the Aruban Batholith will have a different effect on the drainage and infiltration of sewage water (Sambeek, Eggenkamp, & Vissers, 2000).
Table 3 lists the proportion of household drainage system over the type of geological unit (see also *Figure 5C* and *5D*). The data shows that nearly half of all households with cesspools/septic tanks (36% from 77%) are situated on the permeable limestone terrace and just over half (41%) are situated on dioritic soils. From all sewer connections 16% of households are situated on the Limestone Terraces against only 3% on dioritic substrate. The low water table during part of the year will have made a sewer system essential to inhabitation on the more populated areas near the coast, albeit that many of these areas are not yet connected.

A study by Finkel and Finkel (1975) stresses the limited capacity of crystalline rock (Aruba Batholith) to absorb sewage from cesspools, although, on the limestone rock similar to in the detritus valleys of dry-rivers or more deep along the geological fault lines, sewage is expected to percolate even more easily into the groundwater. Groundwater underneath the hard crystalline rocks of the batholith is believed to follow a pattern of fracture lines and weak spots where differential weathering took place. At the border between Batholith and porous Limestone Terraces, dry-rivers often seem to end, but actually follow a path underneath the eroded limestone rock towards the sea or cut through the layer completely.

So, during flooding not only contaminants from the topsoil, but the contents of cesspools may also pollute surface waters and flow into the sea. The constant leaking of cesspools poses a serious risk to the groundwater quality and more directly to the water quality of nearby wells and aquifers (Finkel & Finkel, 1975). The vulnerability in flood prone regions along the limestone coast poses a risk in particular.

Septic water infiltration, however, also has a desalination effect on the groundwater that is particularly relevant during the dry-season along the coast, when, due to the water hydraulics and the high evaporation on land, salt water infiltration tends to be strongest. More inland, residential water discharge dilutes the salinity of the groundwater that has become brackish under the influence of the salt-spray winds (Sambeek, Eggenkamp, & Vissers, 2000).

Aside from the *hydrological mechanisms*, *chemical interactions and binding* with subsoil constituents will determine the speed at which contaminants and nutrients from human action on land are released into the fragile marine ecosystem. For instance, percolated *phosphorous* compounds of waste water bind easily with, and may even dissolve limestone (be it that this is a slow process over many years). In excess availability however, the not fixated compounds diffuse into the sea. *Nitrates* may rinse even more directly through the porous limestone and reach the ground- and coastal waters. Hydrogeological insight in the subterranean interconnection of groundwater systems and the interaction with surface water, the groundwater upwelling at sea and the hydraulics and transmissibility of the different rock compositions are highly relevant to better understand the detrimental effects of seawater contamination and nutrient enrichments.

Another process worth to consider is that consequential to the leaking of cesspools and watering of plants, in particular inside the enclosed residential plots, the suburban habitat is likely to change towards a more nutrient-rich, humid and less saline ecosystem.

Changes in the micro-climate[16] conditions

Besides contamination and nutrient-enrichment, soil humidity is likely to locally increase by the fencing and construction density that break the effect from the northeast trade winds and water runoff patterns. Even though Aruba has no large city-like urban area, the change in suburban climate conditions may still occur and create a situation comparable to what is called the '*urban heat effect*', more cautiously called '*suburban heat effect*' to mimic the situation in Aruba.

The *urban heat effect* (EPA, 2014) is a condition first described in larger cities when dense built-up areas retain the daily heat from the sun more so than the surrounding (rural) areas. Urban construction materials compared to rural land cover create a climate condition that differs by evaporation and thermal capacity (Bharat, 2009). The urban heat effect influences the climate in and above modern cities and causes serious problems such as *higher energy demands, water expenditures,* and the *accumulation of air pollution*. (Golden, 2004).

We expect that the factors that underlie the 'urban heat effect' are to some degree locally present in 'suburban' Aruba as well, because under the hot sub-tropical conditions the effect in micro-climate will be more pronounced. In Aruba, more hot air will remain in between buildings, in particular at lower heights, due to the increase in radiation from the cemented surface structures, decrease in evaporation from the absence of vegetation, and the absence of the natural cooling effect from the northeast trade winds.

[16] A microclimate is defined as local atmospheric conditions in a confined area that are different from its surroundings (see: wikipedia.org/wiki/Microclimate). The main parameters to define a microclimate within a certain area are temperature and humidity.

In addition, the changed suburban environment may also provide more competitive opportunities for species, such as insects, insect feeding birds, reptiles, weeds and grasses[17] that thrive well in disturbed, nutrient-rich and more humid environments. In contrast, in these suburban settings, we may expect conflict with nature as there is an increase in the use of pesticides[18], herbicides, fungicides and repellents to fight off intruding pests[19]. What is more, in the areas where there is dense housing and infrastructures, micro-climatic circumstances may change, as wind and water flow patterns become obstructed or funneled by buildings, walls and infrastructures. There may be an increase of erosion and turbid winds in one place and a standstill of waters or almost no wind at other locations.

Concluding remarks

In summary, today's major global environmental concerns can be categorized into:

- Chemical pollution and greenhouse gasses
- Nutrient enrichment
- Landscape fragmentation and loss
- Biodiversity loss
- Invasion by locally alien species

In the present series on the landscape we made a start to provide information about the status of these issues in Aruba. Roughly stated, at the interface between the economy, the environment and the society in Aruba we described the following conflicting situations:

- *Suburban expansion and land use*
  (Derix, Landscape series No.4: The Suburbanization of the Aruban Landscape, 2016d)
- *Living conditions and consumption patterns*
  (Derix, Landscape series No.5: Housing and accommodation in recent decades in Aruba, 2016e)
- *Waste, pollution, eutrophication, flooding and noise*

The latter aspect is detailed in the current paper. The information we provide may help to understand how the challenges we face in our own home environment and the actions we take translate into the challenges for the landscape and for the coastal marine environment.
For instance:

- ❖ *We may cause a suboptimal fertilization of local soils due to an unbalanced match between chemical substances in the specific substrate and the fertilizer compounds with the net result that much of the nutrients actually remain unbound and be wasted into the groundwater and into the sea.*
- ❖ *We may cause pollutive discharge in the home garden from the continuous leaking of cesspools, the disposal of chemicals with the wastewater from for instance paint jobs, batteries and oil remains, as well as with the disposal of phosphates and nitrates from soaps and detergents that come with dishwashing or cloth washing.*
- ❖ *The landscaping of our garden often comes with the introduction of exotic plant species that may require larger amounts of water. These 'richer' environments may provide better opportunities for some of the more adaptable local species, but may provide opportunities for competitive invasive species as well.*
- ❖ *Changes in near surface micro-climate conditions and richer topsoil may help the survival of alien weeds and insects that require costly pest control measures.*
- ❖ *The use of fungicides, herbicides, insecticides, etc., adds much harm to the local environment. We use toxic or bio-persistent chemicals because in large we lack information about suitable alternatives to pesticides.*
- ❖ *Unrestrained urban planning and house construction have an impact on the natural course of the rainwater, which comes with unpredictable costs during period of heavy rainfall.*
- ❖ *There is likely a heat buildup from predominantly asphalted and concrete surface area in the suburban environment that has negative consequences for water and electricity consumption. The use of local trees may bring less evaporative cooling (as they consume and evaporate little water), but will bring much shade and a more pleasant outdoor environment.*
- ❖ *The single-stoned outer walls of our houses often lack shade and allow the heat from the sun to radiate inside. As the buildup of heat during the day is longer retained at night in the heated suburban environment there will be an additional energy demand for air cooling.*
- ❖ *Soil compaction causes less water retention and an increase in urban stormwater runoff and erosion.*

The challenges above illustrate some of the factors relevant to establishing an environmentally sustainable home neighborhood. With more relevant information, alternative approaches can be thought of that not only serve the sustainable effort, but also save household expenditures.

[17] Unfortunately more invasive non-endemic species also adapt easily to the new environments.

[18] Some pesticides are known to inhibit nitrogen fixation in soils because they kill the respective bacteria and fungi that do so.

[19] We refer to http://en.wikipedia.org/wiki/Pesticide for a general description of the typology and chemo-physical characteristics of the different categories. Here we included all the goods within the category 38.08 of the Harmonic System

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